AIMS and STRATEGIES of LABORATORY WORK

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INTRODUCTION

The lab-work addressed here is the one that implies working with real objects. In order to define the role of laboratory work in the teaching of physics it may be useful to adopt two perspectives. The first one looks at it from the viewpoint of the Physics discipline, an experimental science. The second perspective considers the laboratory work as a didactical tool for the understanding of the discipline as far as its structure, laws, models, concepts are concerned. From the mere meaning of these two viewpoints it follows that the discussion of the epistemological aspect in which experiments are related to phenomena, models and theories, should precede the discussion of the didactical aspect. Firstly our view of the role of laboratory work in Physics is presented, then we discuss its didactical role.

THE ROLE OF LABORATORY WORK IN PHYSICS

Physics is an experimental science whose aim is the observation, description, modelling and understanding of the natural world in which we live. Since Galileo this understanding takes advantage of the reproduction of phenomena in a laboratory setting with the help of apparatuses that enable the scientists to study, in quantitative details, some of the aspects of a specific phenomena. A crucial role is played by neglecting what may be deemed secondary. As Galileo says: "neglect all that is considered contingent and accessory in order to be able to generalize and quantify".

Let's imagine to enter in a Physics laboratory[1] while an experiment is being performed: there are people and objects. The persons may be busy in controlling and optimizing features and functioning of the apparatuses, in reading instruments or computer displays, in exchanging ideas and comments, in getting feedback from data and literature, in writing a careful logbook of what is going on, etc.... The real objects present in this laboratory may be totally unfamiliar to someone used to the common every-day experience in the natural world. There, in the scenario we are imagining, are also many objects invisible to human sight but well present and real in the mind of the physicists: theories, models, the knowledge shared by the scientific community and also expectations and goals aimed at by many individuals. These invisible objects are the basis, on one side, of the development and performance of the concrete objects which have been chosen and organized for the conduction of the experiment and, on another side, of the questions that the scientists-experimenters have chosen for searching answers

[1] The images of very big laboratories, e.g. CERN in EU, are more complex ones. Here we refer to an ordinary small or medium scale laboratory at University level.

throughout the experiment, its results, its success or failure. These research questions may be of different kinds. For instance, one may: investigate about the validity and/or the verification of a theory or theoretical hypothesis; try to get quantitative information on some new phenomenon; try to see changes in a known phenomenology due to the advances in technology; try to reproduce a measurement done elsewhere and with other techniques or to confute an experiment thought to be inaccurate or affected by errors, and so on… In all cases there is a research question that has triggered both the design of the apparatuses present in the laboratory we imagine to visit, and the methodology of data collection and analysis. To clarify the interplay between the theoretical knowledge and the experimental activity[2] it may be useful to present a schematic view of experimental research.

Four phases or steps can be identified in the research process:

a) The first step is the search and definition of the research question or the problem that needs an answer throughout an experiment. The capacity of finding a problem that is meaningful at a particular stage of the development of the scientific knowledge is strongly related to the creativity and experience of the researchers, within the boundaries of what is already known. What is agreed upon in the scientific community is usually a strong boundary condition for the search of the research question, as shown by several examples of strong resistance to consider unorthodox viewpoints.

b) A second phase deals with designing the experiment, searching or inventing the hardware and software of the apparatuses and assembling the setup. In this process it is necessary to analyze the phenomenological aspects, to define which variables should be controlled or measured, to invent or optimise technical solutions, to build the apparatuses, to evaluate the performance by some trial measurements. Again creativity and experience are needed, in particular, for the technical aspects; the required knowledge concerns both the theoretical side and the rules of the experimental activity. These rules include check of the apparatus efficiency, measurement procedures, methods for data analysis (with special attention paid to errors and approximations), tools for sharing data and facilitate communication amongst the participants to the experiments[3], etc... In the process of building and optimising the apparatus, however, the data may be used often at a qualitative level more than at a quantitative one, since the main goal is to check that the apparatus has been properly designed and built, other than to define the precision of the obtainable results.

c) The third step comes into the game once the validity of the apparatus and the measurements procedures have been carefully checked and optimised and it is time for data collection and the complete measure campaign. This phase, that may, at regime, become more or less a kind of routine, requires attention, patience and care with respect to all rules of the experimental game. From the creativity viewpoint it may be the less

[2] The phases described below are almost always present also in the theoretical activities, here the aim is to reflect on the experimental research

[3] The most important example of such a tool is the www, invented at CERN in 1991 to facilitate the joint work in the big experimental collaborations involving many laboratories in different part of the world. At that time no one thought of the current immense use of the web nor of the changes it is producing in very many activities

interesting phase, even if in some cases the problems that may arise during the data collection are not minor ones and need intelligent and creative on-the-spot solutions.

d) Creativity becomes again important in the fourth phase of data analysis, when the produced results are interpreted in the light of existing theories, or for proposing modification of existing theoretical frameworks, or, why not, to propose completely new hypotheses.

The above scheme seems to show a time sequence but it has to be underlined that in real experiments, specially the complex ones, these four phases often have fuzzy boundaries, so they overlap and mix.

THE DIDACTICAL USE OF THE LABORATORY WORK

From an educational viewpoint, the lab-work can aim at different objectives. A first one is connected to the epistemological perspective where the laboratory is seen as the place appropriate to communicate the experimental game, in its relation to formalization, models, theories and the like. The scheme proposed previously demands that lab-activities should involve the students in all the four phases, from the identification of the research question or problem to be addressed to the design and construction of the apparatus, to data collection and analysis. The interpretations of lab-work can be rather different in different situations; the EU project "Lab-work in Science Education" (LSE Project, 1998) has shown that lab-work is widely acknowledged as a significant teaching/learning activity, but it is proposed in different degrees in current class practice. Roughly the same type of Lab-work is proposed across countries and disciplines - small groups of students working with real objects or materials following precise and detailed instructions given directly by the teacher or written on a worksheet; open-ended projects are rarely addressed. Assessment is usually done by grading lab-work reports. Usually in the traditional interpretation of lab-work, both at University and school, what is proposed to the students is the mere collection of data using an apparatus already designed and prepared in all its details, with little or no explication of the research question or why it is addressed via an experiment. These types of lab-work activities are aimed mainly at have the students manipulate measuring tools, collect data and analyse them in the light of a known, already studied model. In other words the students are required to focus essentially only the third phase, while in the fourth one they do not have to search for a theoretical interpretation. This kind of activity may be of some help for the training of young researchers if performed with up-to-date measuring tools but is of scarce or no help for understanding the role of experimental work and its relationships with the processes of modelling and formalization. In the following some didactical activities, focusing on the communication of the interplay theory-experiment, are briefly discussed.

Another use of the laboratory has to do with the possibility of a better understanding, with respect to the verbal communication, of concepts, models, laws and theories. The axiom, "if I do I understand" is very often quoted to affirm a link between manual and mental activities. This viewpoint is one of the basis of the so-called "hands-on" approaches that are becoming more and more popular. However it should not be taken for granted that being engaged in a manual activity will stimulate by itself the mind and assure sound and long lasting learning. The trap that "doing" something is sufficient warranty to understand what has been done is an old one, linked with naïve forms of empiricism. Unfortunately, still nowadays the emphasis on a mere "doing" is present, often in the framework of "discovery" approaches as, again naively, if it was possible with some school experiments to re-walk the complex process of building crucial aspects of the disciplinary structure of physics. To improve the positive features of the "hands on" strategy, the more complete keyword "hands and minds on" should be used and practised to stress the need of a careful and synergic mix of manual work and mental reflection.

To foster and support the learning process, it is necessary a careful planning of the lab-work, in order to communicate that understanding physics concepts, models, laws requires not only to "see" and explore the phenomena, but also to identify regularities and rules, to express them in different languages (natural and formal ones), to model them, to be able to produce or inhibit a process, to change the behaviour of a system, to interpret the results of an experiment in the light of the knowledge needed to design/realise it and to assure its validity.

In the following we describe briefly some didactical experiments that may facilitate the interaction of the students' minds with the studied phenomena and their interpretation in the light of a constructivistic learning model.

SOME DIDACTICAL ACTIVITIES

For the sake of brevity it is not possible to aim at a complete presentation of emblematic lab-work activities that can help improving the quality of physics education. We only focus on some points of general value and on some plausible suggestions. The latter are discussed having in mind possible boundary conditions due to resources usually existing in the schools, as for instance hardware, time, syllabi, technical support.

a) Some reflections on the didactical methodology

Physics Education Research (PER) has shown the fundamental importance of the ideas hold by the students, about the physical world and about what science is, in their interpretation and understanding of what they are taught (Ogborn 2000, 2006, this volume). Various strategies have been proposed and experimented in order to elicit, address and compose the conflicts between students' naïve ideas and reasoning strategies with the physics knowledge developed and agreed upon by the scientific community. A crucial point is the importance of an interactive dynamics amongst teacher and students (Arons 1995, 1997, Viennot 2004, this volume) and amongst students in peer learning interaction (Mazur, 1997). As far as laboratory work is concerned the interactivity that should be stimulated and facilitated involves not only students and teachers but also the addressed phenomenon and the apparatuses/tools used. Therefore both the rationale and the organization of the lab-work should trigger and support such interactivity and foster the acquisition of disciplinary and communication skills. This means, in particular, that the teacher, during the lab-work activities should pay attention and use different communication modalities. The main ones can be schematised as follows:

- asking, which here means to request the students to express their predictions on what is going to happen in the experiment; to compare such predictions with the obtained data, identifying similarities and discrepancies; to iterate the process if needed (for instance in the framework of the Prediction Experiment Comparison (PEC) learning cycle, briefly described in the following;

- listening, which here means to facilitate the students in discussing different experimental set-ups and their justification, but also to understand and cope with students' naïve ideas and reasoning

- acting concretely, which here means to support the students in building the experimental set-up

- telling, which here means to guide (not in a step-by-step style) the students toward the convergence on both experimental learning objectives and a disciplinary correct interpretation of what lab-work is;

- valuing different viewpoints to appreciate the richness of diversity

- clarifying problematic issues and links with other physics topics and/or disciplines;

- using different communication registers in order to take care of the different cognitive styles and types of intelligence of the students in the group.

Fortunately, as for any other educational activity, there is no a unique and warranted way for handling the laboratory activities. It is so also because these activities can aim at various objectives, as for instance the exploration and understanding of: a specific phenomenon; the role of experiments in science; the meaning of modelling as a bridge between phenomena and theories; the problems related to uncertainty, precision, accuracy of measurements; the distinction between relevant and irrelevant variables; the identification of the most appropriate features of the tools to be used; etc …

b) Some suggestions for activities

Here some emblematic but not exhaustive examples of lab-work are briefly discussed. The order of presentation tends to suggest the amount of needed resources, e.g. hardware, software and time.

i) Lab-work based on low-cost or no-cost materials

This type of laboratory activities uses materials that can be bought in the every-day life shops/markets or found in the natural environment or re-cycled from other activities. Some emblematic examples are experiments for studying basic physics topics as: oscillations via pendula made with bolts and fishing line or unripe, compact small fruits and natural fibres; equilibrium via balances made with cloth hangers; hydrostatic basic laws via plastic water bottles or containers of perfusion solution recycled from medical uses; floating and sinking physics via combining bottle cork or local soft wood and nails to build variable density systems having the same volume; passive elements circuits via torch bulbs and batteries; reflection and refraction phenomena via cheap laser pointers and small plastic acquaria; images produced by lenses via transparent plastic containers of diverse dimensions; electric motors via small magnets and home made coils; the basic of optical fibres via the above laser pointers, water jets, fragments of fibres; etc… Several cheap technological gadgets can also be exploited, specially the ones which are familiar to many students who use them without knowing the basic of how the gadget functions.

This type of lab-work allows experiments in almost any context, especially in those situations where laboratory resources are lacking or scarce. It can be easily reproduced, disseminated and adapted to the features of the local context, for instance as far as the materials are concerned. The low-cost or no-cost lab-work encourages the teachers towards experimental activities, specially those who previously have not had much exposure to lab-work, especially the ones who do not have access to traditional laboratory apparatuses usually found at schools or do not feel confident in using these tools. It can be of great educational impact where lab-work is not usually practiced, as may be the case of school physics courses and practice in emerging countries. It can help teachers and students to acquire competences in setting up apparatuses; finding creative solutions for experimental explorations; distinguishing between qualitative observations and quantitative data collections; developing a way of looking at familiar objects as possible components of experimental set-ups appropriate for exploring phenomena and measure them. This type of activities can also be suggested as an home work more motivating than the usual exercises at the end of the textbook chapters. The low-cost or no-cost lab-work does not pretend to substitute or exclude those experiments usually performed at school via traditional apparatuses especially designed for didactical measurements. It is complementary to other types of experimental activities and it is a way for helping teachers and students to become familiar with lab-work as a normal, not special part of the class practice; it does not require special costly set-ups or dedicated spaces and tools. This type of lab-work is valuable also for its capacity of demystifying the rather common myth that good experimental work at school needs expensive apparatuses and that those made with low-cost materials may only be useful for science popularization and edutainment. This myth about costly tools usually produces several problems: schools may renounce to provide laboratory activities when there are not enough resources to buy costly apparatuses; teachers often perceive the latter as difficult setups, are shy in using them and pretend the assistance of laboratory technicians; headmasters, worried by the risk of damages and replacements, suggest to use costly equipment sparingly; students often perceive lab-work based on traditional apparatuses as boring and another instance of the gap between what is taught at school and their interests.

ii) Demonstration or “ex-cathedra” experiments

This type of experiments, done by the teacher in front of the class, were rather common in the past; nowadays they are not much used being often considered as less apt than laboratory activities since the manual part is done only by the teacher and the students do not “touch” or manipulate any tool. However they may be very useful for stimulating the mental activity by appropriate strategies of interaction. Their use is not limited to those contexts where resources are scarce; their role is to trigger the curiosity of the class, to elicit naïve ideas and reasoning of the students, to prepare the ground for other experimental activities.

The strategies may differ according to the aims of the demonstration:

a) when the goal is to present the students experiments that cannot be performed in a laboratory session because of lack of enough apparatuses, use of difficult-to-find or dangerous materials, scarcity of space, etc…; the teacher can stimulate the discussion for the clarification of conceptual or experimental issues or problems;

b) when the goal is to trigger conceptual understanding; also a single experimental apparatus may be used with a class, even a large one. In recent years the "Interactive Lecture Demonstrations" (ILD) based on the use of Real-Time experiments (Sokoloff & Thornton, 1997; the essay by R. K. Thornton in this volume and its references) have become popular, specially in USA. The rationale is to interact with a large number of students by asking them, before the experimental demonstration, to express their predictions in a form collected but not graded by the teacher. The predictions are then compared with the experimental results obtained in the demonstration and possible conflicts are discussed. Many ILD for introductory areas of physics are now available.

c) When the aim is that of addressing students' ideas and reasoning on particular topics, also some "show experiments" may be useful, specially about phenomena familiar to the students who explain them in terms of commonsense knowledge. The "show" aspects helps to capture the students' attention. The request of an explanation, often not a trivial one, is a king of challenge and aims at discussing basic physics contents.

Some emblematic examples are:

- the melting of ice

The teacher uses two tablets of the same dimensions, one of wood or plastic and one of metal and two equal ice cubes (like the ones produced by a kitchen freezer). At the beginning several questions are asked to the students, as: what will happen if one ice cube is placed on each tablet? Which ice cube will melt first? How long is the difference between the melting times?

The teacher records the students' predictions on the melting time together with the justifications, as indicators of the their knowledge, ideas and reasoning. At the start of the experiment the students are asked to observe carefully the behaviour of the ice cubes, to compare it with their predictions and explanation and eventually change them according to what they have seen. The much longer time required for the melting of the ice cube on the insulating tablet is always a surprise, often also for physicists.

- coloured shadows

The teacher asks the students if and how it is possible to produce a red or green shadow of an object and records the key points of the answers and the following discussion. Then s/he shows the shadows that can be easily produced by two slide projectors with a green and a red filter. The addressable topics may go from the definition of a shadow to its geometrical properties; to the possibility of explaining the shadows by geometrical optics; to which hypotheses underlie the geometrical optics model; to what a model is, its descriptive/interpretative properties and limitations; to what colours are and how humans perceive them; to the difference between addictive and subtractive properties of colours; to the effect of the filters on the white light of the projector lamp, etc...

- finger in the water

The students are asked to predict what will happen if a finger is put, without touching the container's walls, in one of two containers filled with water which are in equilibrium on a two arms balance. Three possibilities are generally envisaged by the students: the container with the finger does not move, it goes down or up. After these predictions are compared in a group discussion together their justifications, the teacher performs the experiment. In the discussion, often the problem of the finger weight is raised, no matter that at the beginning the teacher has clarified that the finger never "leaves the body" of the person doing the experiments. This "show" is a good introduction to discuss the third Newton's law and some naïve ideas about it, together with the buoyancy phenomena.

- cans rolling down a ramp

To perform the experiments at least four empty soft drinks cans (same shape and size), are needed[4], together with some kind of powder, e.g. instant coffee. The teacher prepares the cans as follows: one is left empty, one is completed filled with powder, the others ones are partially filled with different amount of powder. The teacher releases the cans from rest and same height on a ramp or on a curved guide. The students are asked to observe carefully how the cans move[5] and to explain what they have observed. Since they are not used to discuss the motion of inhomogeneous objects, when asked to order the cans according to a correlation between their weight and the number of oscillations made, very often they try to explain the experimental results in terms of friction force and predict a monotone correlation. The hand weighting of the cans then produces a surprise. This experiment is useful to discuss friction and allows an approach based not on the force concept but on the energy one. Traditional exercises/problems about energy are usually solved in absence of friction. A learning/teaching difficulty is commonly encountered when shifting from the viewpoint of friction force to that of energy dissipation. This experiment may also be appropriate to introduce both the internal energy in a mechanical system and a particle model when some degrees of freedom may be frozen.

ii) Real-Time experiments

Since the 80's, computer driven sensors systems, here named Real-Time Experiments and Images (RTEI) to stress the role of graphical representation of measures, have started to be used in tertiary and secondary education. New didactic access and paths to traditional or new topics have become practicable; e.g. what is practically "invisible", or didactically inaccessible, is made "visible" because of the many details present in the very many collectable data (transients, impulsive forces, etc…). Strategies to cope with common learning-teaching difficulties can be strongly supported by RTEI especially when these systems are used to implement open learning environments, inspired to constructivistic learning models that offer the learner a substantial control of experimental and data

[4] Also some plastic small cylindrical container, coming out of some chocolate eggs, quite common in EU, can be used.

[5] On the curved guide the completely full container and the empty one behave in the same way, performing several oscillations before stopping. The partially filled containers do oscillate too but the numbers of oscillations is smaller.

analysis activities, without pre-decided pedagogical paths. Nowadays the didactic approaches based on RTEI are not yet fully naturalised in current class-practice (Sassi, 2001). Nor are they thought of by teachers as crucial approaches to be proposed in many learning situations. At the beginning the main reasons for such a slow naturalization have been related to insufficient hardware resources or similar logistic factors, but these aspects have been, on the average, improved. Also the teacher's competences and skills play important roles; in teacher education programs more emphasis should be paid to Real-Time experiments.

RTEI approaches make easier the implementation of variational approaches, the PEC (Prediction Experiment Comparison) learning – teaching cycle (White & Gunstone, 1992) and the "Real to Ideal" rationale (Sassi, 2001).

The affordable fast repetition of experiments allows exploring what consequences derive from the variation of experimental conditions. A "what happens if this changes" attitude is easily encouraged and practised; a high cognitive goal can be therefore aimed at, valuable in many disciplines and contexts.

The PEC cycle helps students to grasp important aspects of physical methodology. The "Prediction" phase facilitates the expression of students naive knowledge, ideas, reasoning and of their learning difficulties; the "Experiment" one can also be used to address possible conflicts between what underlies the prediction and what is actually measurable; the "Comparison" of experimental data is helpful also to separate relevant aspects from minor details and to identify significant variables, relationships and regularities.

According to the "Real to Ideal" rationale, the students "walk" didactic paths that go from real/familiar phenomena to ideal cases/models, rather than in the opposite direction as presented in many textbooks. The path starts from real-time experiments exploring complex phenomena, well known in terms of commonsense knowledge, in order to elicit naive reasoning and ideas. It proceeds to identify phenomenological regularities that are expressed in regular language and, when possible, in formal one. The regularities are then transformed in rules, through more "clean" experiments, in which some effects have been minimised (e.g. friction). A further step is to model these rules mathematically, possibly first through simple models and later through more complex ones and to abstract towards the appropriate ideal case.

The value of modelling activities is more and more emphasised, especially from the viewpoint of helping teachers and students become familiar with capabilities and limits of models. Rather common difficulties relate with the fact that the same mathematical model can describe diverse phenomena (according to what the model variables mean), and that the capability of interpreting and using already built models is other with respect to building the "best" model for the case in study. Most RTEI systems provide friendly tools for data fitting, so students can experience the descriptive capabilities and the limits of the model represented by the fit.

Students' active involvement is a quite important element for successful teaching/learning processes. Several features of RTEI facilitate the student's motivation: immediate feedback, "up-to-datedness" of the use of computer, challenging game-like approaches, collaborative peer learning. Common learning/teaching difficulties can be successfully addressed (Thornton & Sokoloff, 1998).

Finally, one of the greatest advantage of the RTEI approaches is that they can facilitate the integration of diverse types of knowledge, a cognitive value that often is scarce in current teaching. This integration addresses perceptual knowledge (e.g. experiments based on the link to perception); commonsense knowledge (e.g. eliciting naïve ideas and predictions); abstract representational knowledge (e.g. time graphs of measures and multi-representation of the same data); experimental knowledge (e.g. experiments' settings and measures); variational knowledge (e.g. analysis of the consequences of changes in conditions and parameters); correlative knowledge (e.g. relating different representations of the same phenomenon and comparing experiments and models). For sake of brevity we do not describe specific RTEI activities; in the essay by R. K. Thornton some examples are discussed.

iii) The "project work" approach is appropriate for communicating an epistemological aspect, i.e. the role of experiments in Physics. The teacher suggests a research theme to be explored by the students through the design of the apparatus, the choice of the measuring tools, the collection and analysing of data. Other than identifying a specific research question, the students are required to collect the information required for the design of the experiment, to take care of all the steps of the experimental game briefly described previously, as a collaborative and cooperative group. This kind of work on average requires a reasonably long time, not few hours, but allows to acquire several different competences.. If the context allows only few hours to experimental work and the use of traditional school apparatuses, there is still the possibility of communicating the experimental game through the following possible steps:

- clarification of the research question and its place/role in the context of the knowledge that the students may be supposed to have,

- communication of how the design of the apparatus has been planned to answer the question. If possible, it may be appropriate to assemble the apparatus starting from pieces and measuring tools,

- appreciation of possible errors in data collection,

- discussion and comparison of the results amongst different groups of students.

CONCLUSIONS

We have briefly suggested some examples of "good" experimental activities for the class practice. We want to stress, however, that, as far as experimental activities are concerned, an optimal scenario is a mix of lab-work types, always performed according to an interactive methodology, that is imperative in a constructivist framework.

The types of lab-work one should mix, with relative weights depending both on the socio-cultural environments and availability of resources, are:

- experimental activities using apparatuses built with low-cost, easily found materials and or no-cost ones. It allows both qualitative observation of phenomena and collection of quantitative data.

- experiments with traditional instruments that often are common school resources. They can be used to help students become aware of advantages/problems of lab-work and, when the apparatuses allow only one type of experiment, to experience the difference between "closed" and open lab-work

- Demonstrations "ex-cathedra" to present experiments that cannot be performed by students, for various reasons. These activities aim at stimulate conceptual understanding, either by an interactive approach with a large group, or by so-called "show experiments" that recall students' ideas on particular topics and challenge the class to solve a problem

- Real-Time experiments. When sensors and computers are available, these experimental activities can be very rich (cfr. above). One for all advantages, the students easily can become familiar with a variational approach (what happens if we change …?) that is a methodological pillar of the disciplinary structure of Physics

- Remote controlled experiments. They can be very useful in the case of experiments requiring special resources and equipment and located only in some institutions. By Internet connection, the user interacts with the apparatus, collects and analyses real data. These experiments can also be used to trigger and facilitate collaboration amongst different groups of people in different locations.

- Virtual laboratory. It is a virtual environment where the learner "interacts with an experiment or an activity ..intrinsically remote or which has no immediate physical reality" (cfr. the essay by P.A. Hatherly in this volume). Experiments can be performed through collection of virtual data. It can be useful in several ways, for instance: before and after experimenting with real apparatuses, to make some tests or to explore regions of measures not allowed by the real tools; when no real apparatus is available; to experience what means operating in a real laboratory and in a virtual one. In any case the differences with a real laboratory should be accurately clarified to the students and to the teachers, as in the case of the use of simulations, to avoid or contain the temptation of replacing lab-work with activities in virtual environments. Both virtual laboratory and simulations cannot "replace" experimental work with real objects; it is more time consuming, but being a less controllable place where unforeseen events and/or "mistakes" can happen, by addressing the latter it offers many possibilities to clarify them and point out links with other topics.

To conclude, lab-work, in its many forms, is a crucial part of the construction of a sound, long lasting Physics knowledge. Teachers and students should be helped in grasping the meaning of experimental activities in science and of their links with formalization, models and theory. Too many physics courses at school and University are still "chalk and talk" teaching. The lack or scarcity of stimulating lab-work contributes to the low efficacy of the current physics education. Teacher Education programs should put more and due emphasis on meaning and role of lab-work in Physics education, at any level of school and students' age. This recommendation is justified not only not only in terms of the disciplinary structure of Physics, but also by the need of contrasting a teaching style that id still practised, i.e. to teach Physics as if it was a narration where formulas and anecdotes interplay, and where the experimental aspects are not crucial ones.

We have tried to present here a sketchy panorama of the possibilities offered by Physics Education Research (also with the help of ICT and Educational Technologies) that can be used as a step to change, in Physics courses, from the recipe kind of lab-work to experimental activities that may stimulate sound and long lasting learning.

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