Computer Physics Communications

Computers in Physics Education

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Abstract

We start with an exposition of the situation the physics education community is living at the beginning of the 21st century. We revise the findings of Physics Education Research and then make a short survey on the different possible uses of computers in education as well as point out what are the best practices in classroom and present some outstanding experiences and uses.

Keywords: Computers in Physics Education; Physics Education Research.

1. The state of Physics Education at the beginning of the 21st century

Traditionally, the question of whether students really learn the fundamental concepts of physics after succeeding introductory courses has always worried faculty. The answer to this question being, in some cases, a strong feeling of failure.

This feeling has been incremented in some countries, as the results of international comparison tests have shown how their students, coming from theoretically more advanced countries, perform worse than the average. But what has definitely contributed to raise a great concern in the community has been the long-lasting decline on the figures of enrollments of physics majors.

However, this concern affects not only individuals and educational institutions who care about keeping their own jobs or educational market share, but also governmental agencies and professional organizations who are aware that the

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Note: Being a survey, this paper contains many literal quotations and re-elaboration of ideas from other authors. Quotes have been suppressed for readability, but proper references are readily included.

technology that fueled the recent economic expansion was built by former students trained in math, science and engineering, and grounded on basic research [9].

The reason for this disinterest in physics can be manifold. In the first place, the general public, even scientifically educated public, no longer perceives physics as a vital discipline making ground-breaking discoveries. Also, industries, driven by global competition, and governments inspired by the change in the global political situation and the more stable state of the oil industry have undertaken big cuts in basic research programs on which physics played an important role [9].

Finally, there are also changes in our students and in the educational system itself. Affected by changes in the workplace and being their primary target the search for a good job, students complain if they are forced to learn things that they don't appreciate as directly related to their career goals. Also, having grown up in the era of computers, video and television they are not so fluent with printed material and their mathematical skills have also suffered [9]. Students got accustomed to easy success [8] and Physics requires hard work and provides limited rewards.

2. Physics Education Research

Leaving aside the socio-economic aspects of the problem, to which they have limited capacity of addressing, more and more educators have turned their eyes to what and how they actually teach[1]. And strong criticism has been made.

Some complain, very graphically, that the curriculum is "a mile wide and an inch deep" [24]. Perhaps because most introductory courses cover so many topics only superficially with the intention to provide a basis for a later study.

Concerning the method, typical lessons are of the recitation type and rather inefficient [5]. Assessment insists on this trend, evaluating students using standard tests that ask them to regurgitate facts or plug numbers into equations [9].

A side-effect result of both problems is that students don't experiment the feeling of a growth in competency, which finally turns into lack of motivation and interest [18].

A group of physicists conducted over the past two decades important work on the discipline called Physics Education Research, the result of which is an important body of knowledge on how students learn physics that has reached a high degree of community consensus. These results are now leading to important efforts to design new science curricula [8], [10], [13].

The main concept of this body of knowledge is called *Interactive Engagement*. Interactive Engagement (IE) is a brand name for teaching methods that are designed to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities that yield immediate feedback through discussion with peers and/or instructors [7].

The key point in IE is the acceptance of the principle of the constructivist account of learning which traces back to the work of Swiss psychologist Jean Piaget in the first half of the 20th century. According to this principle, science students must engage in active construction of their own representation of extant scientific knowledge [16]. IE also bases on the fact that students come to us with strongly held ideas about how the world works, many of which seriously conflict with what we have to teach them [19]. Changing these misconceptions is a difficult but ineludible task.

A final principle, originated in the work of the Russian psychologist Lev Vygotsky, states that, for most individuals, learning is most effectively carried out via social interactions [21].

3. The use of computers in Physics Education.

Soon in this process, several researchers and teachers turned their eyes to computers. Some

[1] Although the history of science education research traces back even further.

pioneers [1] announced (in 1981): "We are at the onset of a major revolution in education, a revolution unparalleled since the invention of the printing press. The computer will be the instrument of this revolution…. By year 2000, the major way of learning at all levels in almost all subject areas will be through the interactive use of computers". Prophecy that, obviously, has not yet been fulfilled.

This romanticized view, which announced that the mere presence of technology would enhance student learning, contrasted with those who considered it a waste of time and money [2].

Early studies soon realized that the truth lied somewhere in the middle. Computers showed a great potential to enhance student achievement, but only if they were used appropriately, as part of a coherent education approach [2].

A first typical risk that the designer of instructional software is exposed to, is to forget that the student should run the computer, not the other way round [23]. A second one is to become the unintentional creator of a video game. Students use the software to learn by trial and error, without the full intellectual engagement that was desired [14]. A final risk comes from forgetting students' point of view in favor of ours. Computers make it possible to approach topics from a perspective different to the traditional one and certainly much more exciting… for us. Presentations that enthrall the expert may bewilder the novice [20], simply because their mental models differ.

But before the feeling of too many risks gets high, we must emphasize that these studies, and many others since then, did show a positive instructional gain under certain circumstances and encountered real possibilities to learning and teaching improvement.

On the one hand, new technologies provide opportunities for creating learning environments that extend the possibilities of old technologies (books, blackboard…). On the other, they offer brand new possibilities not accessible before. New technologies can be used to [2]:

- bring exciting curricula based on real-world problems into the classroom,
- provide scaffolds and tools to enhance learning,
- give students and teachers more opportunities for feedback, reflection and revision,
- build local and global communities that include teachers, administrators, students, parents, practicing scientists…
- expand opportunities for teacher learning.

Thus, an enormous amount of educational physics software arose. In an attempt to give an overview, we will provide a rough classification of instructional software according to its principles of use, as well as summarize what the correct pedagogical use should be [2], [6], [11], [12], [15].

Tools for the acquisition and manipulation of data include examples ranging from the use of simple spreadsheets to the more advanced microcomputer based laboratories (MBL) and video analysis.

Young people are usually interested in topics related to the real world that surrounds them. They also need to succeed early to maintain positive attitudes towards science. Thus, early experiences should emphasize observation, data collecting and drawing conclusions [13].

It is particularly in these early stages that MBL can be very appropriate to help students undertake their own investigations. MBL can help students collect data from a variety of sensors, some of which they can even take home or to the playfield, experience in groups and later on use computer software to analyze the data.

Video analysis provides the opportunity to study the physics of real-world events in which students may be interested or involved, such as sport. They can collect and analyze applicable experimental data out of the digitized video sequence. This helps them realize that real-world problems are far more complex than our approximated theoretical models and also helps them acquire laboratory analytical skills [3].

Both approaches can help make Physics less formidable, especially to students with limited mathematical skills. Moreover, the real-time graphical display of measurements helps bring together symbolic representations with the actual physical phenomenon [6].

Multimedia software is based on the concept of hypermedia, and presents information in a structured, usually graphical, way. Interactive navigation controls allow students to follow their desired path, not necessarily sequential, through a big amount of information provided either as text, images, animations, simulations or video-clips [6].

This type of software takes direct advantage of the ability of the human mind to process and remember visual information, as well as of interactivity, a key feature for learning [2], and flexibility. Advocates for multimedia base its effectiveness in the fact that our brain processes information by free association in an intrinsically non-linear way [6]. Others distinguish learners that present a visual thinking type from those with a verbal thinking type. The former group will benefit from the illustration of dynamic processes in the multimedia, while the latter will profit more from the textual parts of the environment [4].

Microworlds and simulations. Microworlds consist of very complete computer programs, constructed by experts, which implement a simulation of a wide range of physical processes and laws. The program encourages students to explore and interact with the system by including elements in the world, changing parameters and observing the result of this manipulation.

Simulations are smaller scale programs that contain a model of a system or a process and are devoted to the graphical visualization of it. Sometimes, the visualization can be very simple, others it is very sophisticated, including Virtual Reality techniques.

These are certainly the most extended and studied categories of instructional software used in physics education. Computer microworlds and simulations should be open learning environments that provide students with the opportunity to [11]:

- develop their understanding about the phenomena and physical laws through a process of hypothesis-making and idea-testing,
- isolate and manipulate parameters and therefore help students to develop an understanding of the relationships between physical concepts, variables and phenomena,
- employ a variety of representations (images, animations, graphs, numerical data) that are helpful in understanding the underlying concepts, relations and processes,
- investigate phenomena that would not be possible to experience in a classroom or laboratory.

Although they also benefit from an image-oriented representation of knowledge, computer simulations reach their educational goals only when combined with adequate instructional methods. Three types of measures have been identified [12]. In the first place, those that provide direct access to domain information and present it concurrently with the simulation, at the appropriate time. Secondly, those that provide learners with assignments (or questions, exercises, or games). Finally, in the case of simulations with complex models, a model progression scheme permits a more appropriate learning pace.

If used this way, simulations have been widely reported to provide a more intuitive and deeply processed knowledge than with expository teaching. Also, simulations seem to show better results when the instructional goal is a mastery of discovery skills [12].

The awards-winning *Interactive Physics*, *XyZet* and the simulations *Planets and Satellites* and *Jacobs* are certainly wonderful choices[2].

However, within the group of simulations, our number-one choice is, definitely, *Physlets* [3]. Physlets is the family name of a series of small, flexible Java applets that can be used to simulate different type of physical phenomena. Physlets are also controllable using scripts, which allows teachers to customize them to prepare their own simulations at a very low learning cost. Used

[2] The reader can surely find references for these products using a web-searching engine.

together with just-in-time teaching methods[3], Physlets can turn into very powerful educational tools [17].

Collections of simulations are also available of the web, either forming an organized on-line Physics course or just showing nice examples of visualization.

There are also some very complete environments that bring together simulations and cognitive tools that provide appropriate instructional support. A good example is the award-wining *Simquest*.

Modeling tools are software environments that allow students to build their own computer simulations. Modeling tools benefit from the same educational advantages of simulations plus add the possibility of allowing the students make their conceptions explicit.

The students are given a set of tools (from pure programming to high-level building blocks) that help them describe relationships among concepts, run the resulting models and compare their results with the accepted wisdom or with laboratory experiments. The confrontation of their simulations, usually with conceptual errors, with the community accepted models results in the student perception of her misconceptions, thus facilitating the transition.

Modeling tools can also help students understand equations as physical relationships among quantities, make sense of translation among representations, give students engaging, hands-on learning experiences and serve as sketchpads on which students can explain their understanding to each other and to instructors, thus helping visualize student's thinking [22].

Our favorite modeling tools are *Modellus*, whenever simple models are sufficient, and *Easy Java Simulations* for advanced modeling.

Telematics and Internet tools exploit the capability of computer intercommunication making use of all of the previous types of software. Definitely the most emerging technology, with more and more prestigious institutions placing first quality educational material on the Web, the pedagogical advantage of using telematic tools should not only reside in the easy access to all kinds of documents and to vast amounts of real-world data.

Since the ultimate goal of education is to prepare the students to become competent adults and life-long learners, it makes sense to link students not only with their peers, but also with practicing professionals. Thus, an increasing number of projects are creating virtual communities with common interests that include staff from educational and research institutions. Anyone in the network can push (usually local) data to the community, which they, students and researchers, analyze, posting their conclusions back to the net. The result is an increase both in knowledge and in skills, since the students have access to the same tools and procedures that scientists use [2].

Some references of interest are the *Worldwatcher*, *W.I.S.E.*, *System Erde* and *GLOBE* projects, to name just a few.

Remote laboratories are a second area of activity in the Internet. Instead of accessing data collected by others, students are given access to remotely controlled real experiments. Equipment is prepared so that students have a reasonable capability of reconfiguring it. They can run the experiment, sometimes remotely watching at it using a web camera, and then collect the results from it for local analysis.

Finally, networks are increasingly being used to connect homework with classroom activities. When combined with quickly adjustable classroom material, teachers can assign homework problems which are due short before the lecture starts, collect the students responses and, according to what the students submit, adjust and organize classroom lessons to address the issues that the student show problems to understand. This conforms a 'just-in-time' teaching strategy that is more tuned to the students' needs [17].

[3] To be described later.

4. Conclusion

Good educational software, developed with a full understanding of applicable principles, has not yet become the norm [2]. Anyone designing or using educational software should be aware of the findings and recommendations of Physics Education Research. Otherwise he or she is bound to be 'reinventing the flat tire' [21].

The need to apply good instructional software in the classroom also faces the traditional resistance of individual teachers and of Physics departments to accept solutions coming from the outside (and sometimes even from other faculty members of the same department). Not to mention the lack of communication between the communities of physicists involved in disciplinary research and of those involved in education research [5].

For these reasons, flexible, customizable educational software is especially adequate, so that teachers can tailor the product to match her particular interests and educational points of view, and combine the use of a correct pedagogical approach with the sense of giving to it their own flavor.

In this paper we have tried to provide a few entry points from which anyone interested can get started in this interesting and promising field.

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