B - LEARNING PHYSICS FROM THE EXPERIMENTS

Discussion Workshop B Report

Reporter: Chris Chiaverina[2]
[2]*New Trier High School (retired), 385 Winnetka Avenue, Winnetka, Illinois, USA*
fizzforfun@aol.com
DW Leader: Michael Vollmer[1]
[1]*University of Applied Sciences Brandenburg, Magdeburgerstr. 50, 14770 Brandenburg, Germany,*
vollmer@fh-brandenburg.de

Physics strives towards an understanding of the material universe. To gain this understanding, physicists systematically question nature through experiments. These experiments are designed to challenge existing hypotheses and provide clues to more powerful theories. However, experiments are not only essential in expanding our knowledge of our universe, but play a key role in the teaching of physics. Experiments allow students to observe phenomena, test hypotheses, and apply their understanding of the physical world. Perhaps of equal importance, experiments have the power to motivate. Which experiments should be used in the teaching of physics and how should they be employed to maximize their effectiveness? This report addresses these questions and suggests some possible answers.

Introduction

We begin our discussion with a Chinese proverb. This proverb, and an extension, nicely describes why experiments are a key element in physics education.

- I hear and I forget
- I see and I remember
- I do and I understand
- I do with self-build apparatus and I never forget

More specifically, experiments are used in schools to:

- motivate students
- provide concrete examples of complex concepts
- increase understanding of technical apparatus
- verify predictions, theories or models

Certainly, experiments are necessary for the advancement of scientific knowledge. However, experiments are equally important in the teaching of physics for they afford the students direct contact with natural phenomena.

There are, naturally, many questions and problems related to the use of experiments in physics teaching at various school levels. The same experiment may be used differently depending on whether the desired outcome is motivation, deepened understanding, or the confirmation of a model or hypothesis.

This work is based on results from a discussion workshop during the 2005 GIREP seminar in Ljubljana with about 20 participants from around a dozen different countries. It attempts to summarize some essential ideas, questions, problems and propose possible answers concerning the role of learning physics from experiments. The following list of questions and problems does not claim to be comprehensive. It should be regarded as a summary of often encountered problems associated with the use of experiments in physics teaching. The ranking of topics, in order of importance as deemed by the discussion group, is displayed in Table 1. Following the table is a summary of the discussions spawned by the topics listed.

Table 1: Questions or problems associated with the use of experiments in physics education
Questions of higher priority in our group *A) More general* 1) What is a good balance between experiments and theory? 2) What is a good balance between various types of experiments during teaching (i.e. scientific, hands on, teacher centered, student centered)? 3) What is a good balance between experiments and computer animations/modelling during teaching? 4) What is the role of experiments (hands on, scientific, student experiments, etc.)? *B) More specific* 1) Examples for experiments in so called modern physics, let us say 20th century physics 2) How far may we simplify and still be correct?
Questions of lower priority in our group *A) More general* 1) How to evaluate the effectiveness of experiments for teaching *B) More specific* 1) How to select, prepare and perform experiments 2) How to select different ways of including experiments in teaching 3) How to incorporate real research for students

The role of experiments in physics teaching

Physics is a science based on experiences, observations and experimentally found facts. Theoretical ideas are important, but only if their consequences can be verified by observations or experiments. Although some facts are found serendipitously, most of them result from carefully planned experiments. Hence, experiments are an indispensable ingredient in scientific investigations in physics and, in fact, all natural sciences.

Since physics is offered to school children of different ages and backgrounds, it is, of course, taught with various degrees of simplification. However, just as in scientific research, the experiment retains a central role, and is indeed indispensable, in the teaching of physics, regardless of the degree of rigor.

Generally speaking, there are two types of experiments that may be employed in the teaching of physics. There are science-oriented, or quantitative, experiments, designed primarily to allow the study phenomena under reproducible conditions, e.g. measuring the acceleration g of freely falling bodies in the gravitational field of the earth, using a metal sphere and light barriers. Quite often these experiments are intended to give students an opportunity to quantitatively test a theoretical hypothesis. The necessity of these types of experiments for the advancement of physics is obvious, for they are an essential in the preparation of future scientists.

A second type of experiment is motivational in nature and designed primarily to provide students with a qualitative encounter with physical or technical phenomena or processes. Low cost and hands-on experiments belong to this latter category. Whereas the former type of experiment often only attracts a limited number of students, the latter offers the possibility of reaching more students and raising interest in the natural sciences in general.

The world of the 21^{st} century is dominated by an ever-growing number of technological innovations. A growing number of students leave school without a basic understanding of the physical principles that are the basis of these technological developments. Therefore, considering the low level of science literacy in most cultures, the usefulness of motivational experiments for the advancement of a public understanding of science would seem to be beyond question.

Excellent laboratory-based physics teaching is certainly a prerequisite to averting scientific illiteracy. However, when teaching physics in schools, a delicate balance between the two types of experiments identified above must be used in order to 1) properly motivate students to achieve a certain level of understanding of the natural sciences in general and 2) convince them of the need for quantitative measurements for the advancement of science. The balance is certainly determined by the age, intellectual maturity and the preconceptions of the students. In addition, this balance often depends on a number of external forces such as a school's financial resources, cultural differences of the students, requirements of the curricula or technological developments. Obviously, there is no simple answer to what is the best balance. In the end, the chosen balance will depend on the topic being taught, the clientele, the didactic concept of the individual teacher, and external factors.

Types of experiments and resources

Besides making a distinction between quantitative and motivational experiments, it is possible to further refine distinctions between the different types of experiments used in schools (see tables 2 and 3). As these tables indicate, the type of experiment performed is often dictated by the nature of the pedagogy employed. In a teacher-centered classroom, lecture demonstrations are frequently used to illustrate physical principles. In a more student-centered classroom, students learn by becoming more actively engaged in exploration and experimentation.

Table 2: Various types of experiments used in physics teaching

Who is performing	Type of experiment
- Teacher - Teacher / students - Teacher / students - Students - Teacher / students - Students - Teacher / students	- conventional lecture demonstrations - hands-on demonstration experiments, (e.g. [1]) - "real" quantitative experiments with scientific apparatus, ideal conditions, eliminating typical disturbances like friction … - student experiments as homework - distant laboratories with remote control of experiments [2]

- Third party / teacher / students	- educational science games - "computer experiments" - science shows

Table 3: Various resources for experiments used in physics teaching

resource	cost
Hardware for real experiments in schools - Professional equipment (teaching aids from commercial sources) - Experimental kits/boxes (developed by educators) - Everyday materials	- expensive - medium priced - inexpensive
Out of school encounters with real experiments **-** Science centers, amusement parks [3] - School / student labs (like in Germany) [4] - Visit of scientific institutions (CERN, Fermilab, etc.)	- moderate, but with travel expenses - free, but travel expenses involved, advance registration needed - free, but travel expenses involved, advance registration needed
Use of virtual or distant experiments - Remote control of experiments at distant sites [2] - Television - Computer programs, CD-Rom´s and DVD´s	- free, advance registration needed - free - moderate
For teachers only: in service training offers - Teacher training seminars - Personal contacts/exchange at conferences like [5,6] national meetings … - Teacher Journals [7] - Outreach activities (ESA, NASA, CERN, Fermilab...)	- moderate - moderate, but travel expenses involved - moderate - free

On the effectiveness of experiments in physics teaching

The effectiveness of experiments in the teaching of physics is difficult to measure. Evaluation can be greatly affected by the instrument used. For example, in one study, mentioned by Paul Doherty, two highly qualified physics teachers taught the same physics course, one time with and another time without experiments. Following instruction, student achievement on tests was found to be the same. It has been argued that the evaluation tool used in this instance was biased and consequently influenced the result.

Performance studies may also be affected by the way in which the evaluation is done. For example, multiple choice type tests are often ineffective when it comes to evaluating student understanding. Studies using inappropriate instruments can be dangerous since they may be used by politicians to argue that experiments are not necessary.

In the end, it may be that the enthusiasm and personality of the teacher and the mind set of the students, both of which are intangible entities, are the most important factors in determining the effectiveness of experiments.

School experiments for 20th century physics

To many teachers, the scope of modern physics is limited to Bohr's model of the atom and Einstein's theory of relativity, i.e. physics which is 90 to 100 years old. Modern physics is of course much more. Quantum mechanics, particle physics, cosmology, and material science are of great interest to students and should be included in today's physics curriculum. A collection of simple, age-appropriate experiments are needed to adequately teach these rather difficult topics.

Examples of experiments for teaching the theory of relativity, quantum physics, superconductivity, semiconductors, computer technologies, material sciences/soft matter, and so on, are readily available. Some examples are listed in Table 4.

Table 4: Examples of selected experiments in modern physics education

1) Using students to represent the sun, earth, Jupiter, and one of Jupiter's moons in a demonstration of one the first determinations of the speed of light (contribution Girepseminar 2005).
2) Using rubber balls to represent the interaction of photons and electrons in the photoelectric effect. (Micklavzina, Girepseminar 2005).
3) Performing an experiment illustrating light energy versus color (these and others, see [8]).
4) Demonstrating the affect of relativity on the functioning of GPS [9].
5) Demonstrating computer technologies using eight strips made from magnetic tape [8].
6) Prelude to superconductivity using jumping rings at room temperature and at LN2 temperature.
7) Silly Putty experiments to illustrate soft matter (contact Mojca.cepic@ijs.si)
8) A collection of demonstrations illustrating relativistic effects (contact per-olof.nilsson@chalmers.se)
9) Chaos experiments (search www.google or http://www.psigate.ac.uk/newsite/ for lecture demonstrations and chaos)

Outlook: the future of experiments in physics teaching

The technological advances that have occurred over the last few decades have had an enormous influence on the equipment available for experiments in schools. The invention of the transistor and semiconductor-based electronic devices such as the computer has brought about a dramatic change in laboratory technologies. Similar scientific and technological advances will certainly continue to be made in the future. As in the past, these will change the apparatus and other experimental resources available to school teachers.

What will be the future of using experiments to teach physics in 2050? Members of our discussion group shared their visions regarding technological developments and the use and availability of old and new tools (movies, DVDs, www, distant lab learning facilities with remote control of experiments, science centers etc.). These visions/feelings are listed in Table 5 without any further discussion.

Table 5: Visions of the use of experiments in physics teaching of 2050
1) Experiments will continue to play a central role in physics education, however more will be computer based. Computer aided experiments will allow the inclusion of frictional and other effects in simple experiments.
2) Experiments will always be needed to motivate students.
3) If we transfer our enthusiasm regarding the use of experiments to new teachers, experiments will remain a key element in physics education. That is, the experiments may stay the same, even though the materials used to demonstrate them may change.
4) Simple hands on experiments will always have their place.
5) Teachers will remain central to physics education. Ultimately the learning derived from experiments depends on three factors: the enthusiasm of the teacher, the teachers mastery of the topic and the teachers experience.
6) We will continue to use every available tool to teach physics, including new technologies. Problems associated with the teaching of physics will not change, however the tools to deal with them will.
7) A goal of physics teaching will continue to be the development of critical thinking skills.

References

[1] http://www.exploratorium.edu/explore/handson.html

[2] http://www.remote-lab.de/en/index.html

[3] http://www.ecsite.net/new/index.asp , http://www.astc.org/

[4] http://www.helmholtz.de/de/Helmholtz_als_Partner/Schuelerlabore.html

[5] Girep organization http://www.girep.org/ there are links to all conferences and seminars and one may easily find links to the respectice on-line proceedings

[6] http://www.scienceonstage.net/main/default.asp

[7] Physics Education: http://www.iop.org/EJ/journal/PhysEd; European Journal of Physics: http://www.iop.org/EJ/journal/EJP/ ; The Physics Teacher: http://scitation.aip.org/tpt/ ; American Journal of Physics: http://www.kzoo.edu/ajp/

[8] http://www.exo.net/~pauld/

[9] http://www.sfsite.com/fsf/2000/pmpd0005.htm