Role of experiments in physics instruction – a process approach

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ABSTRACT

This paper draws on the ways in which physics is practiced, and presents a variety of ways to use experiments in a physics classroom similar to the ways that experiments are used in physics research.

INTRODUCTION

Papers, books, Internet sites, and AAPT workshops provide list numerous experiments for use in physics instruction. How can an instructor decide what experiments to use? How can she/he move away from traditional "cookbook" experiments in labs and from lecture demonstrations that have been reported to achieve little[1]? This paper describes an approach to classroom experiments in which they serve roles closer to that in the practice of physics[2].

We propose that in the history of physics most of “classical” experiments fall into one of three groups: *observational experiments*, *testing theoretical model experiments*, and *application experiments*. Initial observational experiments occur when physicists study an unknown phenomenon, they help develop a new model. For example observations of the behavior of gases in the 17th century, observations of the spectra of gases in the 19th century, or Becquerel’s observations of a photographic paper wrapped around uranium-laden cross. Before physicists conducted these experiments, they could not make theoretical predictions of what was going to happen.

Testing experiments are usually conducted to test or disprove a certain hypothesis, idea, or a prediction. For example Hertz's experiments tested Maxwell's predictions of electromagnetic waves. The Stern-Gerlach experiment tested the idea of space quantization. Physicists performing these experiments could use a theoretical model to make a prediction about what they expected to observe if their model was correct. Application experiments utilize and synthesize physics concepts developed and tested earlier, for example planning a satellite exploration of a comet or designing a method to detect blood glucose.

EXPERIMENTS IN PHYSICS INSTRUCTION

Experiments in traditional physics instruction are used as lecture and high school classroom demonstrations and as laboratory experiments[3,4]. There are two pedagogical techniques used for lecture demonstrations. In a traditional course students observe an experiment and then the instructor explains what happened and why. In reformed instruction students predict what is going to happen before the experiment, and then reconcile their predictions with the observations that follow. The latter has proven to be more effective that the former[5]. Students make predictions using their naïve conceptions and then modify these conceptions based on the outcome of the experiments. Traditional laboratory experiments usually have as a goal to verify a principle or a concept that the students already learned from the instructor. The emphasis is on quantitative analysis of data with a great deal of guidance on how to execute the experiment. The theory is often provided with the laboratory instructions.

In some non-traditional introductory physics courses such as *Workshop Physics*,[6] experiments play a different role. Students make observations and invent a concept that explains them. This approach is much closer to the practice of real practice.

We suggest that this method can be taken father. We propose that all physics experiments used in instruction can be classified according to the goal of the experiment[7]:

1) Observational experiment. The goal is to observe a new phenomenon. Students later devise explanations for the observations.

2) Testing experiment. The goal is to test whether the explanation devised for some observed phenomenon works. Students use explanations that they constructed to explain some type 1) experiment to predict an outcome of a new experiment.

3). Application experiment. The goal is to apply the explanation that has been tested in 2) to explain new phenomena or design technical devices.

Using different pedagogical treatments for these types of experiments, instructor can teach the students to differentiate between observational evidence and inferences. Students learn to test inferences experimentally and see the applicability of their ideas. They acquire science process skills. This purpose of this paper is to encourage instructors change the approach to the experiments that they already use in lectures or laboratories without adding any new activities. Table 1 provides suggestions for instructors on how to implement this approach to the experiments. In the following section we provide examples of each type of experiments. A reader can view observational and testing experiments described in the paper in real time and frame-by-frame: http://www.pt3.gse.rutgers.edu/physics/frontp.html. The web page contains a collection of 45 videotaped experiments supplemented with questions that an instructor might use in a lecture or laboratory.

[Insert Table 1 here]

INITIAL OBSERVATIONAL EXPERIMENTS

Throw a basketball straight up while standing and let students observe the vertical motion of the arms and the ball. The same throw is repeated while the thrower is walking, or running, or rollerblading[8] along a straight line with constant speed. Students observe that the ball, which has been thrown vertically upward lands in the instructor's hands at a different horizontal location. The experiment can be repeated with different walking or running speeds and with different initial vertical speeds. The same experiment can be done with a dynamics cart that launches a ball vertically when it passes an electronic trigger (you can view these experiments in Projectile Motion unit on the webpage). One possible explanation devised by students is that the ball continued to move horizontally wile moving vertically or that horizontal motion and the vertical motion are independent of each other.

TESTING EXPERIMENTS

Qualitative

The instructor then asks the students to design an experiment to test if the explanation above is correct. An example of a testing experiment suggested by students: walk with constant pace or rollerblade with constant pace holding a ball above your head. If the idea that horizontal and vertical motions are independent is correct, then if you drop the ball, it should land by your feet. The instructor might also ask students to predict the outcome of a new experiment using the explanation above. Example: two balls are on the same metal rod with a compressed spring between them. When the spring is released, one of the balls flies off with a horizontal velocity, and the other ball falls straight down. Which ball lands first or do they land at the same time? To answer – view the experiment in the Projectile Motion Unit.

Quantitative

After testing the independence of motions qualitatively, students can test whether the kinematics equations—constant horizontal velocity and constant vertical acceleration apply for projectile motion. For example, at what angle to the horizon should they point a rod that holds a spring stretched a given distance so that when released, the spring lands in a box across the room—on the first try? There is no information provided about the properties of the spring. The students might offer the following solution: First, orient the rod vertically, stretch the spring a certain distance, and release it. They observe the maximum height to which the spring goes after release. They then predict what angle to launch the spring so that it lands in the box on the first try (a variation of this experiment is on the webpage).

APPLICATIONS

Qualitative applications

1. Show a demonstration to the students, ask them to explain it using a concept that was tested before, and decide how they will test their explanation. Example: A candle is lit on a plate with a small layer of water and then covered with a glass jar. Students observe that after a short time, the candle goes out and water goes into the jar.
2. Ask the students to predict the results of a demonstration before they see it using a concept that they have tested before and then reconcile their prediction with the actual experiment. Example: An enclosed box on wheels with a floating helium balloon on a thread attached to the bottom of the box, is made of clear plastic. The students predict what will happen if the box is pushed abruptly (the balloon moves in the direction of the push).
3. Perform a demonstration. Ask students to predict what will happen if some parameter in the experiment is changed using the concepts that they have constructed before. Example: Students observe 45 W and 60 W light bulbs connected in parallel to an outlet (a 45 W bulb is less bright). Then they need to predict which bulb will be brighter if they are connected in series.

Quantitative Applications

1. Students design an experiment to answer a question. For example: how would you determine if a material is an electrical conductor or a non-conductor?

2. Students design a measuring instrument (or a method) and indicate the limits of its measuring ability. An example can be to design a method to measure the mass of an object on a space station orbiting the Earth.

3. Students make a prediction so that something occurs successfully on the first try. For example they need to deflect the electron beam of a cathode ray tube to a selected location using a combination of magnets with known poles.

SUMMARY

This approach to experiments in physics instruction allows an instructor to move away from the treatment of experiments in which they "illustrate" or "verify" physics concepts to an approach that resembles practice in the real world of science. Implementing it, the instructor has to make a choice whether she wants the students to: (1) observe a phenomenon to identify patterns in the data and devise an explanation,; (2) test the validity of their explanation; or (3) consciously apply an explanation or law. We developed a website with 45 videotaped experiments supplemented with questions for the students that are consistent with this approach.

The approach as a part other innovations is currently used in freshmen physics courses at Rutgers University, Ohio State University, University of California, Chico and several high schools. OSU and Rutgers have large-lecture courses, USC Chico has classes of smaller size but the same traditional lecture/lab format. Prior to switching to this approach the professor at OSU used "reformed instruction approach" (see p.2) to lecture demonstrations in combination with other interactive strategies. Scores of his students on Conceptual Survey of Electricity and Magnetism were the highest in the country (average 69% on the post test, 50% average for students in the country[9]). After the first semester of teaching lectures with the approach described in the paper the scores of his students were significantly better than before (average 74%, effect size 0.5).

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Table 1. Different types of experiments, their goals and pedagogical approaches

Type of experiment	Pedagogical goal	When to use in instruction	Instructions for the instructor	Questions for the students	Where it can be used
Initial Observation. Can be qualitative or quantitative	Let students observe a phenomenon to collect data, find patterns in them or devise an explanation	At the beginning of a unit, as a lead for the students to develop conceptual understanding	1. Choose a simple experiment with a clear pattern. 2. Do not provide explanations, elicit predictions or use scientific terms during the experiment. 3. Focus attention of the students on the necessary part. 4. Ask students what they saw. Insist that they use their records and do not make inferences. After they agree on the results of their observation, ask for possible explanations.	1. What did you observe? 2. What did you record? 3. What are possible explanations of your observations? 4. What physical quantities might help you understand the phenomenon? 5. Measure the quantities and record your observations in data tables. 6. Look for patterns by graphing the data. 7. Formulate a question from the pattern, and then propose a hypothesis to answer that question.	Lecture, lab
Testing of a concept. Can be qualitative or quantitative	Let students test the explanations that they invented for an initial observational experiment	After students construct multiple explanations, they either design experiments to test them or predict the outcomes of the instructor chosen experiments based on their explanations	1. Have equipment ready so the students can see it while they are devising testing experiments. 2. Find new experiments whose outcome students can predict using the concept. 3. Have students discuss the outcomes of the experiment in relation to the concept.	1.What is the concept you want to test? 2. What equipment do you need? 3. What is your prediction? Is it based on the concept? 4. Why is there is a mismatch between your prediction and the outcome of the experiment? Do you need to revise the concept or testing experiment? 5. What did you ignore in your analysis that may have caused your prediction to be wrong?	Lecture, lab, Students can also design testing experiments as a part of their homework.
Application of a concept or multiple concepts. Can be qualitative or quantitative	Let students apply the concept that they invented and tested to explain other phenomena or to invent a device	After students have confidence in the explanation or concept that is in agreement with a scientific explanation or concept	1.Choose experiments that are real-life based. 2. Have students articulate the concept that they use to explain them or predict the outcome. 3. Have students evaluate the precision of the device that they will build beforehand.	1.Define a problem. 2.Identify smaller parts of the problem (analysis). 3. Access relevant conceptual knowledge. 3. Identify variables to be used in the analysis and quantities to be measured. Identify and justify approximations. 5. Identify other solutions. 6. Choose criteria to use in deciding which is the best solution. 7. Evaluate solutions.	Lab if students need to build devices and lecture or lab for other tasks

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