

Lecture Demonstrations in Modern Physics: Quality vs. Quantity

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In a study conducted in modern physics courses, our investigation shows that inappropriate and an excessive number of demonstrations can lead to ineffective results. We carefully observed and recorded the activities done in all lectures in two modern physics classes throughout a quarter and analyzed students' responses to the end of the quarter questionnaires. We found a significant number of students did not recall many of the in-class demonstrations and were confused about the results of different demonstrations they had seen in lectures. In this paper, we will explore the possible reasons for this outcome and discuss implications for instructors who use demonstrations in lectures.

1. Introduction

The findings of pedagogical research often favor the use of in-class demonstrations, and these demonstrations are becoming more common in introductory physics courses. In large universities, easy access to a wide variety of demonstrations with professional technical support and the popularity of demonstrations with students (from course evaluations), encourage instructors to fill their lectures with a large number of demonstrations.

Early findings in pedagogical research often favored the use of lecture demonstrations without many constraints and focused on causing more excitement and producing "oohs" and "ahs" from students.[1,2] However, later studies indicate that the effectiveness of these demonstrations in enhancement of learning strongly depends on the degree of students' interaction and involvement.[3]

In most studies, the evaluations of lecture demonstrations in physics class often rely mostly on the students' positive comments about these demonstrations.[4] In fact, one of the most important arguments in favor of in-class demonstrations in the literature of physics education is the overwhelming positive comments on course evaluations. They indicate that demonstrations are fun and exciting, making the lecture less dull and boring. [5, 6]

Furthermore, some physics teachers argue that lecture demonstrations can lead to a better understanding of physics concepts and can

encourage students to think about the physics of the problem. In addition, some teachers claim demonstrations help students develop an intuitive feeling for the real world and can translate abstract ideas into a concrete and practical form. [1, 5]

A significant part of early studies on lecture demonstrations focused on macroscopic topics such as Newtonian mechanics; very little work has been done in the microscopic domain of modern physics, where the macroscopic observation of physical events is not enough to understand the processes that cause the final results.

This study evolved during another modern physics research project.[7] The researcher, who attended lectures for two modern physics classes observed an interesting result when analyzing students' responses to the end-of-quarter surveys. Here we share these results, using examples of demonstrations on the photoelectric effect.

2. Research Methods

Our research methods in this study include three approaches: class observations, an in-class response system, and on-line surveys.

2.1. Class Observations:

We observed every lecture throughout the ten-week quarter for two calculus-based modern physics classes at The Ohio State University and paid close attention to students' attitudes and behaviors and the lecture material. We took detailed notes related to student learning processes and behaviors in class to see how these related to class survey results.

Lectures met three times a week, each for 48 minutes. In addition, there were two recitations per week and seven laboratory sessions during the quarter. The lecture covered the topics of waves (four weeks), geometrical optics (one week), interference and diffraction (one and a half weeks), relativity (one and a half weeks), and introduction to quantum mechanics (two weeks). Each class had about 45-50 attendants who were scattered mostly at the back of a large classroom.

The lecturer for both classes was a condensed matter experimental physicist, who, although an experienced instructor, was teaching the modern physics class for the first time. His overall method was a traditional lecture; however, he included as many demonstrations as possible in the 48 minutes of each lecture. Some lectures had up to three or four demonstrations in addition to slides, simulations, and/or short video clips.

During the demonstrations, the instructor rarely asked questions, and of the questions he asked, most were rhetorical or were answered by the instructor before giving enough time for students to explore their thoughts and to respond. Students' questions, if any, were limited to the end of class.

2.2. In-Class Response System

At the beginning of the quarter, the instructor tried to use multiple-choice and short answer questions to get student feedback through a computerized voting machine.[8] This in-class response system served as both a research and an assessment tool. We divided students into groups of four.[9] Each group obtained a remote answering device to participate in in-class polling. After a few weeks, however, the instructor realized that the in-class response system did not give him enough time for all the demonstrations he had planned for the class. As a result, he stopped using the voting machine, and therefore, eliminated much of the feedback that he could get from the students during the class period.

2.3. Survey Questions

The primary research methods were the voting machine and the class observations. However, when the instructor stopped using the in-class response system, we replaced it with on-line surveys to get feedback and collect data for our research. We asked 112 freshman engineering

students to participate in two online surveys. Students were told that their responses would be appreciated in helping with research and that the questions were ungraded and voluntary.

The first survey was given in the seventh week of the quarter, and the second one during the last week. Both contained multiple-choice and open ended questions, mostly on the physics content from the lectures. Since this was a voluntary task, only 57 (out of 112) students took the first survey and 69 students took the second one.

3. Results

Our observations indicate that the lecturer was knowledgeable about the content of the course and had organized the topics and material well. The variety of different materials being used during the lecture would seem impressive to an observer at the beginning. However, very little time was spent on explaining each demonstration and, more importantly, its connection with the physics concepts intended to be taught. The instructor did not seem to be concerned with the students' engagement and did not ask students to make predictions about the experiments or any other questions before or after the demonstrations. Therefore, the variety of demonstrations often did not attract students' attention.

The use of the voting machine in the first few weeks of the quarter created some engagement on the students' part. This tool might have provided valuable feedback to the instructor if it was used throughout the quarter. When the instructor stopped using the voting machine in lecture, there was no effective assessment of the students' learning and understanding of the concepts during the lecture. (See Ref. 8)

The results of our on-line surveys confirm that students had very little to take home from all the demonstrations they had observed in the class; and all they could remember were parts of an observation or fragments of a concept. For example, there was a demonstration in class on the topic of the photoelectric effect. The apparatus consisted of an ultraviolet light shining on a negatively charged electroscope with a piece of metal attached to the top. Students had observed that the leaves of the electroscope moved close together when an ultraviolet light was shone on the electroscope. Furthermore, the instructor had explained that the photons from the light can

transfer enough energy to the electron in the metal and remove the electron from an atom in the metal. By removing the electrons, the electroscope would be discharged.

In the second survey we had two questions on this topic. In the first question, we explained the exact setting of the demonstration explained above. Then we asked students to recall what happened when the instructor shined the light on the negatively charged electroscope and to explain what happened and why. The point was to see if students could recall anything from this experiment, and also to remind students of the experiment's setting so that we could ask a second question. This question asked students to predict what would happen if the electroscope was charged positively. The students had not seen the results of shining the UV light on a positively charged electroscope in the class. Therefore, we were trying to see if these students could transfer any learned knowledge from one demonstration to a different but related context.

We had expected that most students at least would answer the "what happened" part of the question correctly, even if they could not give a clear explanation for the "why" part of it. To our surprise, more than 42% of the 69 students surveyed did not even remember the experiment. Approximately 23% of the students confused this experiment with many other ones they had seen about light interference. Only about 6% of the students gave a correct and complete answer to this question. The results of students' responses to this question are summarized in Figure-1.

If we add the number of students who did not remember the experiment to the students who were totally confused, the statistical analysis with 95% confidence level ($\zeta=1.96$, $N=69$, $P=0.65$) shows the standard error:

$$\sigma = \zeta \sqrt{p(1-p)/N} = 0.11$$

This means this demonstration was ineffective for $(65\% \pm 11\%)$ of students, which does not include the students with incorrect answers.

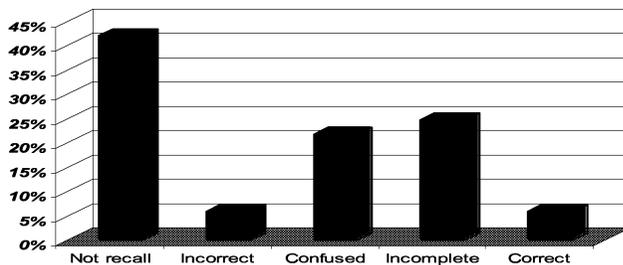


Figure-1. Results of a survey question on effectiveness of an in-class demonstration.

The results of the second question were not any better. More than 37% of the students stated that they did not know the answer, 13% confused this with demonstrations on light interference, and 31% answered incorrectly (see Figure-2).

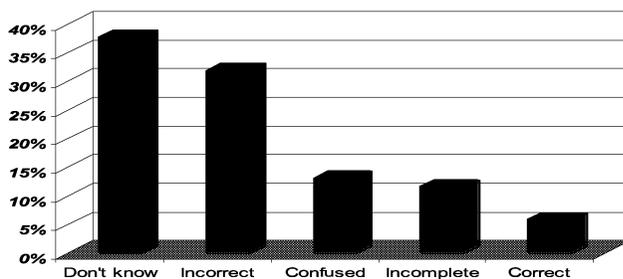


Figure-2. Results of a survey question on transfer of in-class demonstration.

Below we include several students' statements to show details of their confusions.

"You get a diffraction pattern on the screen of light and dark circles," "The only thing that would change would be the slope of the line." "The intensity was greater," "The electrons removed via photoelectric effect show up on the electroscope as bright dots," "It splits the light into its components," "It underwent a diffraction," "It changes the work function and the momentum of the electroscope," "It emits light.."

Some of their responses for the second question (positively charged electroscope) were:

"The (diffraction) line would move up," "The photoelectric effect does not really depend on charge though it does depend on the mass (and therefore frequency) of the particle. Since protons are much more massive than electrons they would then have a smaller wavelength (and subsequently a higher frequency) causing the angle between the bright rings to be smaller. As a result the same

sort of circular diffraction pattern would appear but the spacing between bright rings would be larger,” “The lines would become brighter,” “The diffraction pattern would probably disappear because of the attraction the electrons will experience.”

4. Discussions and Implications

The data in this report, along with the results from other survey questions in our study suggest that in our sample the in-class demonstrations were not effective in enhancement of students' ability to understand and to transfer physics knowledge. Given the previous research about in-class demonstrations, our study suggests the following:

1. Effective demonstrations need time. Briefly mentioning complicated ideas can cause students to be confused. The number of concepts and demonstrations has to be appropriate for the length of the lecture. If the instructor had not rushed each demonstration and cut the total number in each lecture, the results might have been better.

2. Effective demonstrations have to be interactive, engaging, and exciting in order to provoke students' attention. More importantly, in order to have a conceptual understanding of a process, a meaningful connection between concept and observation has to be established. When possible, an assessment of conceptual understanding should be done during demonstrations.[10] Some instructional methods such as Interactive Lecture demonstrations (ILDs) have been designed to enhance the effectiveness of demonstrations.[11] In these method, the systematic use of the learning cycle (prediction, group discussion, observation, and comparison of observations with predictions) ensures student engagement.

3. Another cause for this result can lie in the content of the course. First, topics of modern physics deal with microscopic world, where students can no longer make direct observations. Second, in mechanics it is quite easy to carry out demonstrations which would isolate one effect, and the observation of the demonstration could clarify concepts for students. However, modern physics contains much more abstract reasoning, which in general includes a long chain of cause and effect processes. For this material, methods that introduce microscopic models to explain

macroscopic observations [12] and use of effective simulations to visualize microscopic domains could lead to better results. [13]

The limited examples shown in this paper have suggested possible causes for in-class demonstrations being ineffective. For a better understanding of this problem and to improve the productivity of in-class demonstrations, future systematic research is needed.

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