Seeing is Believing: Classroom Demonstrations as Scientific Inquiry

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Abstract: Demonstrations are a familiar component of any high school physics classroom. There are numerous ways in which effective demonstrations can increase student learning and support the process of scientific inquiry. Conversely, a poorly executed demonstration can leave students confused, misled, or even bored. A practical list of do's and don'ts is included to help all teachers insure that the power of demonstrations in the classroom is not squandered.

The Power of a Demonstration

Mr. Rodriguez and Ms. Chan both use demonstrations regularly in their high school physics classes. Today they are both using a simple marble launcher assembly with two metal marbles to demonstrate that a projectile launched horizontally will hit the floor at exactly the same time as an object in free fall, assuming the two objects were put in motion at the same time from the same height above the floor. Ms. Chan enthusiastically explains the set up of the demonstration as she loads the marbles into the launcher. She asks her students for predictions of which marble will hit the floor first and why. She does not provide them with the answer ahead of time, but rather allows a short, spirited debate before triggering the launcher to settle the issue for her excited students. At the same time in a different classroom, Mr. Rodriguez explains to his students that since the horizontal and vertical motions of a projectile are independent, the two marbles will hit simultaneously. He then triggers the launcher, which he had loaded before class. The students watch with mild interest as the marbles hit the floor simultaneously. When Mr. Rodriguez asks for questions there are none, and he continues his lesson.

Both teachers used the same demonstration to explain the independence of horizontal and vertical motions of a projectile. Yet Ms. Chan's students are eager and engaged, while Mr. Rodriguez's students are hardly paying attention. By the next day, it is safe to assume that Ms. Chan's students will be able explain the physics principle at work, while Mr. Rodriguez's students will probably barely even remember the demonstration.

It seems clear that effective demonstrations can have a powerful effect on the student learning process. But what exactly are those effects, and are they worth pursuing? How are they aligned with *National Science Education Standards* (NSES), if at all? And what are some simple guidelines that can be used to increase the effectiveness of any teacher's classroom demonstrations?

Demonstrations As Inquiry

It may not be immediately obvious how demonstrations are tied into scientific inquiry. After all, the picture of scientific inquiry presented in the NSES brings to mind students performing experiments and collecting data. That seems to be diametrically opposed to the idea of students watching a teacher perform a demonstration. However, in this paper demonstrations are not being proposed as a substitute for relevant student laboratory experiences. Rather, demonstrations can be used as part of an overarching pedagogy that supports inquiry by requiring students to be actively engaged during demonstrations, instead of merely audience members seeking entertainment.

The NSES definition of scientific inquiry is comprised of two components: a set of "fundamental abilities" and a set of "fundamental understandings". In the next two sections of this paper, the fundamental abilities and understandings of inquiry are taken from *Inquiry and the National Science Education Standards* (NRC, 2000, pg. 165-167, 170-171), and are presented in italics. Following each ability and understanding of inquiry is my commentary on how they can be promoted by the use of demonstrations.

Fundamental Abilities of Inquiry from NSES

1. Identify questions and concepts that guide scientific investigations. Demonstrations can be used to prompt student questions about the physical principles on display. This is particularly true when a demonstration taps into a commonly held student misconception. For example, the marble launcher used by Ms. Chan and Mr. Rodriguez intrigues the students with the unexpected result that both marbles strike the floor simultaneously. Using words alone is too often inadequate to present to students a clear picture of the physical phenomena in question. Instead, students need to see the principles in action. This will root the student's understanding of physics in his own sensory experiences, rather than the authoritative voice of the teacher.

2. Design and conduct scientific investigations. Demonstrations can be used to show how various pieces of scientific equipment and apparatus function. This can plant seeds in the students' minds regarding the equipment they would need to conduct their own investigations. Demonstrations also allow the teacher to model how a scientist conducts experiments. Students need to see the teacher progressing through the steps such as setting up and calibrating the equipment, collecting data, and troubleshooting when something goes awry.

3. Use of technology and mathematics to improve investigations and communications. Students should be expected to collect and use data from a teacher-led demonstration. Mathematical relationships between variables can be explored using the data as supporting evidence. Furthermore, doing both a low-tech and a high-tech version of a demonstration can show the effect of technology in scientific investigations, and then comparing the precision of the data collected, for example. Students may be surprised to discover that from time to time the low-tech "tried and true" methods are just as powerful as the newer high-tech methods.

4. Formulate and revise scientific explanations and models using logic and evidence. Recognize and analyze alternative explanations and models. Communicate and defend a scientific argument. As stated above, students should collect data from demonstrations as often as possible. These data can be used to support physical relationships that have already been derived in class. Alternatively, it can be used as the basis for deriving a previously unseen relationship. It can even be used to contradict a previously introduced relationship by introducing new variables to the situation. Whatever models are created or revised, students will have in hand the data to support and defend their conclusions.

Fundamental Understandings of Inquiry from NSES

1. Scientists usually inquire about how physical, living, or designed systems function. Demonstrations that can be used in a physics class to show how physical or mechanical systems function is limited only by the creativity the teacher.

2. Scientists conduct investigations for a variety of reasons. Demonstrations can be used at the beginning of a unit to pique the students' interest in a new phenomenon, just like a scientist has his curiosity around by observing something heretofore unseen. Demonstrations can be used to confirm a previously taught concept, or to show an exception to a rule. This is analogous to a scientist performing additional experiments to confirm or to challenge his working hypothesis.

3. Scientists rely on technology to enhance the gathering and manipulation of data. Mathematics is essential to scientific inquiry. As stated previously, demonstrations in the classroom not only illustrate principles of physics, but also allow students to see various scientific instruments and techniques in action. Collection and analysis of data from a demonstration shows the interplay between math and science, and is vital in order to prevent the demonstrations from becoming merely a show for the students.

5. Scientific explanations must adhere to criteria such as being logically consistent, abiding by the rules of evidence, being open to questions and possible modifications, and being based in historical and current scientific knowledge. Teachers should ask thought-provoking questions based on the results of the debate, and should encourage spirited discussion of the new ideas that will emerge from the students. Student misconceptions are both numerous and deeply held. The experience of a demonstration can force to students to confront their closely held beliefs with the new evidence of their own sensory experiences. Therefore teachers need to be aware of common student misconceptions, and should plan meaningful experiences, including demonstrations, to revise them.

6. Results of scientific inquiry – new knowledge and new methods – emerge from different types of investigations and public communication among scientists. The use of demonstrations as a source of real experimental data and a source of classroom discussion material will promote new understandings of physics in the students.

Do’s And Don’ts of Demonstrations

Clearly there is a strong pedagogical argument to be made in favor of using demonstrations in the classroom. However, if the demonstration is going to achieve any of the lofty aims of the NSES already described, it must be carried out effectively. Here are some guidelines that can be used to increase the effectiveness of any teacher’s demonstrations.

Be prepared. This sounds so elementary, yet it is so easy to overlook. First, the teacher should have a thorough knowledge of the physics principles being demonstrated. Teachers should not attempt to teach what they do not know. Demonstrations should be practiced ahead of time to assure smooth execution in class. A teacher who fumbles about trying to operate the equipment not only looks incompetent, but also runs the very real risk of completely obscuring the point of the demonstration altogether. Being prepared also requires that all of the necessary materials be on hand and functioning properly when class begins. It may be useful to keep a notebook with notes about each demonstration, how to set it up, typical problems encountered, typical student misconceptions, and a record of values that produced good results.

Do not be afraid of failure. Science is not a simple endeavor. Things frequently go wrong for practicing scientists, so teachers should be prepared for that same eventuality. The risk of failure can certainly be mitigated by proper preparation, but it is inevitable that even the most familiar demonstration will go wrong from time to time. Teachers should use these teachable moments to demonstrate how real scientists solve their problems by methodically examining and testing the setup. Teachers should explain to the class what they are checking and why, in order to help students understand the troubleshooting process.

Make the demonstration visible. If students cannot see a demonstration, then they are missing out on an important learning opportunity. Use of proper lighting and contrasting colors, clearing away all unnecessary items from the work area, choosing larger objects over smaller ones, and even elevating the equipment can all improve the visibility of the demonstration. Teachers should take care not to stand in front of the equipment to the maximum extent feasible. Finally, it may be advantageous to allow students to get out of their seats and to gather around the work area, as safety dictates.

Present real science, not a sideshow. Demonstrations serve serious educational purposes. They should not be presented as mere entertainment. This is not to suggest, however, that teachers should not be enthusiastic and engaging. Rather, avoid demonstrations that detract from the class; for example, avoid performing demonstrations of physical principles that will not be taught at some time during the semester. Do not try to fool the students with tricks in the demonstration. The material in a physics class is challenging enough without resorting to tricks, which can result in student misconceptions as well as mistrust of the teacher. Whenever possible, use demonstrations to obtain some kind of quantitative results, even if they are rough. Always allow sufficient time to analyze and discuss the results of a demonstration. Again, a demonstration without an adequate explanation of the physics is simply entertainment.

Keep it as simple as necessary to make the point. The more complicated a demonstration is, the more time required to set up and execute, and the more chance of encountering problems during execution. Simpler setups allow for more class time to be devoted to analysis and discussion. Furthermore, students may be unable to follow a complicated demonstration. Teachers should carefully consider using students as assistants in the execution of a demonstration. Teachers should have the expertise with the equipment and should be able to perform the demonstration smoothly. Due to their inexperience, a student assistant may make procedural errors that can detract from the central purpose of the demonstration. Using computer simulations as demonstrations can save on setup time and allow for easy repeatability. However, over-reliance on computer simulations may lessen the educational impact on the students. For example, a real-life demonstration with the marble launcher is more likely to be a significant , memorable learning experience for the students than simply watching a computer-generated demonstration of the same principle.

Safety. Keep students a safe distance away from all potentially dangerous demonstrations. Make sure the risk of performing a dangerous demonstration is worth the educative reward for the students. If feasible, perform such demonstrations outdoors. Always keep first aid kits, fire extinguishers, and other safety items close at hand, and show students where they are kept. Teachers should always be a model of laboratory safety by wearing, when necessary, appropriate clothing such as lab aprons, work boots, and goggles. Teachers should avoid wearing dangling ties or jewelry when performing demonstrations.

Demonstration evaluation. The demonstration rubric on the next page was developed by the Physics Teacher Education program in the Physics Department at Illinois State University. It can be a useful tool for evaluating the execution of a demonstration. It is not designed for use by the high school students, however. It is intended for faculty members, administration, student teachers, and other teaching professionals.

Concluding Thoughts

It should be self evident at this point that Mr. Rodriguez, the physics teacher from the introduction, has clearly wasted a golden opportunity for student learning by using poor teaching practices with his demonstrations. Properly used, demonstrations can be a meaningful part of any teacher’s curriculum and can support the vision of science education extolled in the National Science Education Standards.

Resources

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