Daniel Graf

Abstract:

This article aims to describe an activity to introduce students to the scientific process using a novel situation: a 3-way light bulb. We often introduce students to light bulbs through exercises involving simple DC circuits with batteries and miniature light bulbs. Though these experiments have great merit in exposing students to ideas of current flow and resistance, they do not fully invoke the scientific process. Using 3-way bulbs, we can extend these experiments to draw testable hypotheses from our students. Using inquiry to explore 3-way bulbs allows us to turn our students into scientists.

Recognizing Traditional Teaching and Lab Work

In recent years, a significant wealth of knowledge has been gained in the art and science of teaching physics. There is becoming perhaps an overwhelming amount of Physics Education Research (PER) to sort through. What can we (as individual teachers) take from all of this information to aid and improve our own teaching? First, I believe we must decide how our students will learn. I believe there is a fundamental battle between passive and active learning, as summed up by Volpe as cited in Michael (2006, p. 159).

“Public understanding of science is appalling. The major contributor to society’s stunning ignorance of science has been our own educational system. The inability of students to appreciate the scope, meaning, and limitations of science reflects out conventional lecture-oriented curriculum with its emphasis on passive learning. The student’s traditional role is that of a passive note-taker and regurgitator of factual information. What is urgently needed is an educational program in which students become interested in actively knowing, rather than passively believing.”

Physics teaching has traditionally consisted of a “sage on the stage” style classroom where students are left to memorize as much as possible of what they hear and read, then solving problems with numbers to get the “answer.” Laboratory work might consist of following step by step instructions to verify that the material taught in class is correct. Almost 30 years ago, Volpe recognized a change was needed; a change away from traditional teacher-centered lectures towards students becoming more active in their own learning.

Engaging Students in their Learning: Lighting the Way

How can teachers create an environment where students are more active in their own learning? I believe we must lift our students above the role of passive “regurgitator” and allow them to become scientists, a philosophy known as *active learning*. Michael offers us this definition from the *Greenwood Dictionary of Education* (Michael, 2006, p. 160)

“Active Learning: The process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas. Requiring students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline. The attainment of knowledge by participating or contributing. The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving.”

An active learning environment in the classroom turns our students into scientists. Students are asked to gather information, think and solve problems – in short, to construct working models based on data they collect. Michael calls this active construction of meaning by the learner *constructivism,* and argues it is the responsibility of the learner, not teacher, to construct meaning. It is up us as teachers to provide opportunities for our students to construct meaning. Driver, Asojo, Leach, Mortimer, and Scott state “The view that knowledge cannot be transmitted but must be constructed by the mental activity of learners underpins contemporary perspectives on science education.” (1994, p. [Page Number(s)] Our students will benefit from a shift away from traditional “sage on the stage” lectures.

Constructing meaning requires the activation of students’ prior knowledge and a thoughtful extension of to apply prior knowledge to new circumstances. Michael further praises constructivism as a link to prior knowledge. “Learners construct meaning from the old information and models that they have… and the new information they acquire, and they do so by linking the new information to that which they already know” (Michael, 2006, p. 160).

Evidence for Active Learning

Why should we bring constructivism and active learning into our classrooms? Where is the evidence that active learning works better than traditional teaching methods? Michael acknowledges that, “as scientists, we have been trained to make decisions based on evidence, and it is appropriate to ask where the evidence is that these proposed new approaches to teaching and learning, these reforms, work better than the old approaches from which we all learned and from which our students seem to be learning.” (Michael, 2006, p. 159).

Using, the Force Concept Inventory (FCI), a valuable assessment tool for the classroom teacher, Richard Hake performed a comparison of learning outcomes from 14 traditional courses (2084 students) and 48 courses using “interactive-engagement” (active learning) techniques (4458 students). The results showed students in the interactive-engagement courses outperformed students in the traditional courses on the FCI assessment by 2 standard deviations. \*\*\*\*\*\*\*\*\*\*

In another side by side comparison, Burrowes compared learning outcomes in two sections of the same course taught by the same teacher. One section was taught in the traditional teacher-centered manner, whereas the other section was taught in a manner that was based on constructivist ideas. The results of this experiment were striking: the mean exam scores of the experimental group were significantly higher than those of the control group, and students in the experimental group did better on questions that specifically tested their ability to ‘think like a scientist.’” Our students will benefit from constructing meaning in an active learning environment.\*\*\*\*\*\*\*\*\*\*\*

Applying Active Learning

If we expect our students to use knowledge to solve any kid of problem, we must provide them with opportunities to practice needed skills and receive feedback about their performance (Michael, 2006, p. 161). I believe this is best accomplished by restructuring our class-time to provide more laboratory opportunities. Certainly, some topics lend themselves more readily to an active learning approach. Direct current electricity is a subject rich in the opportunity for reasoning, for the development of models and theories, for the design of crucial experiments, and for free exploration. “If the students are to realize the benefits of this opportunity, they must be left to their own devices much of the time” (Evans, 1978, p. 16). However, the majority of students require guidance into a series of investigations by being supplied with some initial suggestions and leading questions (not cookbook instructions that destroy all the inquiry) (Arons, 1997, p. 199). McDermott and Shaffer identify three general categories of students’ difficulty with regards to DC circuits; (McDermott & Shaffer, 1992, p. 995).

“an inability to apply formal concepts to an electric circuit”

“an inability to use and interpret formal representations of an electric circuit”

“an inability to reason qualitatively about the behavior of an electric circuit”

The three-way bulb lesson described later provides a guided opportunity for students to use prior knowledge and apply formal concepts to an electric circuit, as well as reason qualitatively about the behavior of electric circuits by examining evidence to construct a working theory.

The task set forth is for students to develop a theory backed by evidence about how a three-way bulb works. The activity is explained in detail in the following section.

In my experience, students often generate better solutions to problems when they work cooperatively with 1 or 2 other students than when they work alone. For this reason, I conduct the three-way bulb activity in groups of 2 or 3 students. This allows for good conversation within the group and a shared strategy in solving the puzzle. Furthermore, Michael cites, “meaningful learning is facilitated by articulating explanations, whether to one’s self, peers or teachers” (Michael, 2006, p. 162). To this end, I recommend having students whiteboard their final solution to the three-way bulb investigation as an evaluative assessment of their learning. Whiteboards can be graded as necessary, but the important thing is for the students to practice sharing their findings with the community (class). The next section of this paper will describe a small electricity unit that incorporates some introductory lessons and later a three-way bulb investigation. There is a heavy emphasis on active learning techniques.

II. Electricity Unit Plan

Day 1

Primary Goal: For electricity to flow, a complete circuit is required.

Secondary Goal: Energy is converted from chemical to electrical in the battery and then to heat and light in the bulb.

Batteries and Bulbs – Students will predict which of ten battery and bulb configurations will light up successfully. They will then proceed to test each setup and record their results. Students will be asked to report what the successful setups have in common and what is missing from the setups that did not work. Lastly, students will be asked to draw what additional setups would work besides the two of ten shown on their paper.

Note – the teacher will look for groups that notice certain setups getting warm and encourage them to write down their observation for future discussion.

“The students decide that, for an element to be part of a complete circuit, there must be an internal conducting path between its two terminals, each of which must be connected to a different terminal of the battery through a continuous conducting path. (McDermott and Shaffer)

Day 2

Primary Goal: Understand electrical energy is converted to heat and light energy in the filament.

Secondary Goal: The amount of light given off can be controlled by the thickness and length of the filament.

Class discussion regarding other discoveries from the day before. Students should become aware that setups that included a complete circuit without the bulb got warm due to a high *current* flowing in the wire. Discuss electrical energy being converted to heat energy. The wire gets warm, just not warm enough to glow “red hot” like a filament. Next, the teacher introduces two or three thicknesses of nichrome wire with a constant voltage impressed across each. The thinnest wire glows the brightest and can even be made to break in two, leading to a discussion about the purpose of the glass to keep oxygen away from the bulb.

Day 3

Primary Goal: Current is not “used up” in a circuit. The amount of current “draw” in a circuit depends on the number and configuration of circuit elements.

Connect 2 bulbs in series and solicit predictions about bulb brightness compared to a 1 bulb circuit. Ask about the amount of current flowing in each circuit. Since the two bulbs are of equal brightness, students recognize that the current from the battery is not used up by the first bulb.

Connect 2 bulbs in parallel and solicit predictions about bulb brightness compared to a 1 bulb circuit. Again, ask about the amount of current flowing in each circuit. Since the two bulbs in parallel will be of equal brightness to the one bulb circuit, students recognize that the current through each bulb must be equal to the current through the lone bulb and therefore the battery must be outputting more total current.

The following three-way bulb lesson can be successfully conducted several days into a unit on electric current and circuits. Students should have some basic understandings of a complete circuit and how a regular light bulb works. The batteries and bulbs activity previously described is a great lead-up activity to a three-way bulb lesson.

1. Introduction – How do three-way bulbs work?
   1. Begin lesson with a three-way lamp in the front of the room. Demonstrate the 4 possibilities: off, low, medium, high.
   2. Challenge students to form a hypothesis about how it works. This is a good point for a think-pair-share. Allow 5 minutes for students to form a hypothesis on their own. Then place them in groups of two or three and allow an additional 5-10 minutes to compare hypothesis. Instruct the students that they will soon design experiments to test their hypothesis.
2. Discuss “rules” of the challenge.
   1. Similar to real life, they will be on a budget. Each group of two to three students will receive $5000 to experiment with and a list of costs associated with various experiments.
   2. They must design experiments (within their budget) that serve to prove or disprove elements of their hypothesis.
   3. They can not break open a three-way bulb. Destructive experiments are not allowed.
   4. They can not look up information specific to three-way bulbs in print or on the internet.
   5. They can earn money back by writing their experimental observations down and submitting to *Electrician’s Digest*, a fictional scholarly journal within the classroom for sharing of information amongst the groups.
3. Ask the students what experiments they could perform to test their hypothesis.
   1. Encourage testable hypothesis.
   2. Students must construct a written hypothesis. Drawings or diagrams are encouraged.
   3. Students should design specific experiments to test various elements of their hypothesis.
4. Students perform experiments to test hypothesis.
   1. When students have designed an experiment and are ready to perform it, deduct an appropriate amount from their budget.
   2. Example “costs” are listed in table 1.
   3. If students desire to do experiments outside the realm of experiments discussed in the table, use your judgment accordingly. My rule of thumb was that experiments based on observation are cheaper than experiments that require action or energy.
5. Students accept or reject original hypothesis based on experimental evidence or research through Electricians Digest.

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period \_\_\_\_\_\_\_\_

Operating Budget = $5,000

|  |  |
| --- | --- |
| **Experiments** | **Cost** |
| Look at a regular bulb  (2 minutes) | 500 |
| Look at a 3 way bulb  (2 minutes) | 1500 |
| Look in a regular lamp with bulb removed  (3 minutes) | 500 |
| Look in a 3-way lamp with bulb removed  (3 minutes) | 1500 |
| Plug in and test a regular bulb  (1 minute) | 1000 |
| Plug in and test a 3-way bulb  (1 minute) | 2000 |
| Look at a 3 way switch  (3 minutes) Attempted cut-away of inside the switch. Pieces were removed in an attempt to see inside the switch mechanism. | 2000 |
| Using a multi-meter in conjunction with any other experiment. (2 additional minutes granted to experiment time) | 500 |
| Plug in and test a 3-way lamp with a regular bulb installed | 2000 |
| Plug in and test a regular lamp with a 3-way bulb installed | 2000 |
| Subscribe to “Electrician’s Digest” | 1000 |
| Payment for journal submissions | 500 |

You will work in groups of two or three. You must develop a hypothesis about how a three-way bulb operates and then decide what experiments are necessary to test your hypothesis. You must pay the appropriate amount of money to perform the desired experiment. You may then fill out a record sheet to detail their observations/conclusions from each experiment performed to submit to the Electrician’s Digest journal. Quality submissions will be rewarded with a $500 payment.

Groups may choose whether to subscribe or not to the class journal for a nominal fee out of their operating budget.

McDermott and Shaffer cite a “Lack of concrete experience with real circuits. Many students have no observational or experiential base that they can use as a foundation for constructing the formal concepts of introductory electricity…In a survey of a large calculus-based physics class, 60% lacked precious experience with simple DC circuits.”

The three-way bulb investigation offers hands-on time for students to see and think about circuits in real life situations. Additionally, they point to students’ “failure to understand and apply the concept of a complete circuit” as a barrier to a thorough understanding.

McDermott and Shaffer conclude, “There is a need for instructional materials that foster active mental participation of students in the learning process.” In my experience students do get engaged in their quest to discover how a three-way bulb works. They usually determine quite rapidly that there must be more than one filament inside the bulb. If we have emphasized bulb brightness being related to the power dissipated at the filament, the equations P=VI=I2R=V2/R and a solid conceptual base should help students figure that the resistance of the filaments in the bulb must be different to achieve different levels of brightness. The most common hypothesis is three filaments inside the bulb. The three-way bulb is a novel way to put students in the driver seat and construct a model using inductive and deductive reasoning and combining simpler concepts into a grand picture, while applying a few engineering details as well. A correct model of the three-way bulb incorporates knowledge of:

1. series and parallel circuits
2. resistance
3. voltage
4. current
5. electrical energy
6. electric power

Closure/final thoughts

How 3 way lesson meets goals

McDermott and Shaffer

“The design of effective instructional strategies for addressing specific difficulties requires knowledge of the reasoning used.”

This 3-way bulb investigation allows us as teachers to listen to our students reasoning for various hypothesis along the way and especially to their reasoning about why different experiments proposed will help them confirm or reject their hypothesis.

A rich investigation could result from testing a three-way bulb with 1 of its filaments burned out. Of the 4 switch settings, off, low, medium and high, the bulb would now have 2 off and 2 on settings, with both “on” settings being exactly the same brightness. This could offer more insightful data towards testing hypothesis.

References

whiteboards

<http://physicsed.buffalostate.edu/AZTEC/BP_WB/index.html>