Fighting Pseudoscience: Homeopathy & Beyond

Joel Schwartz & Therese Block

Purpose

This lesson introduces students to the concept of pseudoscientific thinking, using the topic of Homeopathy as a case study. Logic, reasoning, and pattern recognition are emphasized in an experimental demonstration of Homeopathic dilution, showing how the conclusions reached defy all reasonable claims of validity. A student-driven discussion on additional pseudoscience-related ideas is subsequently held, where recognizing, categorizing, and arguing against dubious scientific claims reinforces critical thinking skills and a skeptical mindset.

Overview

An introductory discussion of Pseudoscience will begin the activity, followed by background information on the topic of Homeopathy. With dilutions and potency in mind, students will proceed with an experiment about various mixtures of food coloring dye. After noting the changes at each increasing dilution, students will compile data on both actual and hypothetical graduated cylinders from the experiment. A class discussion on the connections between the cylinders and concentrations in Homeopathic medicine will take place next, with the importance of drawing analogies to the various dilution levels emphasized. This will lead students to the recognition that Homeopathic claims are extremely dubious at best, and that the field is indeed a Pseudoscience. The activity will conclude with an extensive interest-based discussion of other pseudoscientific topics, offered by the students, where the classification (or mislabeling) as Pseudoscience is explored and analyzed.

Student Outcomes

Students will be able to:

- Define “pseudoscience” and describe how they can recognize examples of it.
- Define “homeopathy” and describe the basic principles it purports.
- Conduct a demonstrative experiment on diluting a mixture by increasing orders of magnitude.
- Apply experimental data/inferences to accurately predict the attributes of higher dilutions.
- Explain via sound scientific reasoning why Homeopathy is best classified as Pseudoscience.
- Share/describe topics of interest that could be/were classified under the Pseudoscience umbrella.
- State why each shared topic could be (or was at one time incorrectly) considered Pseudoscience.

Standards Addressed

MS-PS1-2 (Evaluate properties of substances before/after interaction)
MS-LS2-1 (Analyze/interpret data for effects of resource availability on organisms)
HS-PS1-5 (Apply evidence to explain effects of concentration on reactions)

Reach for the Stars is a GK-12 program supported by the National Science Foundation under grant DGE-0948017. However, any opinions, findings, conclusions, and/or recommendations are those of the investigators and do not necessarily reflect the views of the Foundation.

Time
Approximately two 90-minute class sessions (or between 2-3 hours)

Level
8th Grade Science (as described herein; can be easily scaled to High School with a more quantitative experimental setup, for example.)

Materials and Tools
Computer/Projector
"Understanding Dilution" worksheet and "Extra Info" guide found here. (https://northwestern.box.com/s/9al6olf0t2uzhul35xuupdfnk6234zzg)
Food coloring dye (ideally darker colors like blue or green)
Per group:
- Five 100 mL graduated cylinders
- Ten pipettes (roughly)
- 500 mL tap water

Preparation
Have worksheets printed (1 per student) and experiment materials (1 set per group) ready to distribute before the first session begins. Also have the computer/projector ready to show supplemental information, describe the data table, pull up relevant websites, etc.

Prerequisites
Students should be familiar with exponents, their meaning, and their manipulation under basic algebra. They should also be able to measure volumes in a graduated cylinder and create simple mixtures with little assistance. No previous exposure to Pseudoscience or Homeopathy is required.

Background
When someone tells us "the Earth is round" or "sodium and chlorine are extremely dangerous in their elemental form," we generally assume that there is sound scientific evidence to support such a claim. After all, one purpose of school and education is to convey factual knowledge of the world to the students involved. But is that (or should that be) the only goal?

Suppose someone else says, with extreme conviction, "the United States never sent astronauts to the Moon." Everyone is allowed his or her opinion on a subject, but this does not necessarily mean you should trust that person. There are countless recordings, accounts, documentaries, and memorabilia regarding the NASA Apollo Program, which began in 1961, not to mention that certain telescopes are capable of viewing the spacecraft material left behind on the lunar surface by the six successful missions to land there! Adherence to the idea that the Moon landings never occurred could be classified by the scientific community as a conspiracy theory, which falls under the larger umbrella of Pseudoscience. These are beliefs or practices that mistakenly present themselves as scientific (or based on science), but for several possible reasons fail to meet these expectations.

Given this notion, we can suppose that a similarly important goal of education is to help students recognize and distinguish things that are reasonable versus ridiculous. In the following activity, we will

investigate one of these potential "pseudoscience" practices called Homeopathy, which at its most basic level is based on the principle of "like cures like." We will eventually expand the reasoning we are practicing to a broader level, but for now think about the following:

- What does "pseudoscience" mean to you? Have you seen an example of it before?
- Do you think pseudoscientific things are common or rare?
- What do you think "like cures like" could be referring to?
- How could sound scientific reasoning be important to you or someone you know?

Let's get mixing!

Teaching Notes

At the time of writing, Wikipedia has nice articles on Homeopathy and the associated system of dilutions, both of which are good review starting points before teaching the lesson. To summarize:

Homeopathy was created by Samuel Hahnemann in 1796 on the doctrine of "like cures like," where a substance that causes illness symptoms in a healthy person will necessarily cure the same symptoms in sick individuals. The method of delivery is through "remedies" prepared using Homeopathic dilution, where the substance in question is serially diluted in water (or alcohol) followed by forcefully agitating the mixture. It is the belief of Homeopaths that the further a substance is diluted, the more "potent" it becomes and thus the stronger its curative effect. While already very suspect, the real absurdity presents itself in some of the *extreme* dilution levels claimed, *well* beyond the point where *ANY* of the original substance is statistically likely to remain in the remedy administered. The explanation by proponents is that the solvent retains properties of (or has "memory" of) the substance that was being diluted, a feature that has never been scientifically demonstrated to exist. Furthermore, no Homeopathic remedy has been proven to be any more effective than a typical placebo. Despite these gross inconsistencies, various potencies of such "medicines" are routinely sold in drug stores, health-oriented businesses, and through online distributors, obscuring their ineffectiveness to the uninformed.

The lesson should begin with a conceptual introduction of Pseudoscience (again, the Wikipedia article is a good review point.) There are many examples that could be used; Redi's Experiment from 1668 (i.e. no "spontaneous generation" of maggots from dead flesh) was selected during the original iteration of the lesson. With any conceptual choice the fallacious points should be stated, noting that *any* of three conditions may qualify something as Pseudoscience: A) not following a valid scientific method, B) not reliably testable, and/or C) otherwise lacking scientific status. In the Redi example, spontaneous generation would largely satisfy condition C since the concept was (at a time) ignorantly plausible and certainly testable, but now lacks scientific status because evidence overwhelmingly suggests against it.

After adequately defining Pseudoscience, the activity should transition to focusing on Homeopathy. Begin by defining the discipline, giving some history/context on the methodology, and stating the principles upon which it is based (particularly the dilutions.) Students are likely to have numerous questions as these items are presented, which will be good for gauging involvement. The instructor should convey that Pseudoscience is a very broad subject, and thus the class will initially take a specific look at one topic to get a sense of the ideas involved. Moreover, while the status of Homeopathy as a Pseudoscience should be fairly apparent from the start, detailed explanations as to *why* this is the case should be tackled *after* students have performed the upcoming experiment and tabulated their data/intuition.

State that the class will now turn to investigating Homeopathic dilutions and the associated claims, so have student groups collect the necessary experiment materials. Students should follow the protocol

described at the beginning of their worksheet (state that the "Discussion Piece" on the last page is their assignment for the conclusion of the activity), which has them create 5 distinct mixtures of food coloring dye diluted in tap water. It is OK to convey that this portion is as much "demonstration" as "experiment" and while accuracy should always be strived for, being *absolutely perfect* in the volumes/measurements is not necessary. There are inherent approximations (e.g. dye molecule number) that will be made when filling in the data table (as noted in the "Extra Info" guide), so creating the dilutions should be taken as *qualitative* and indicative of an underlying trend. If more *quantitative* work is desired here- such as for more advanced or High School students- see "Additional Information" below for applying the "Extra Info" guide better.

When all groups have finished their mixtures, follow with a brief discussion of their observations and hypotheses about the container contents. Students are likely to have interesting ideas about the number of dye molecules, so be sure to ask about this specifically! Next start filling out the upper data table, together first then letting the student groups continue. The different columns are (see "Extra Info" guide for more explanation):

- Cylinder Number: which container is being talked about.
- Dye Drops: equivalent number of drops in the container (initially 10).
- Dye Volume: milliliters of dye in the container (initially ~1 mL).
- Dye Molecule Number: total dye particles left in container (initially ~10^{20}).
- In Words: the molecule number expressed as it would be spoken.
- Total Dilution Factor: ratio of dye volume to cylinder #0 (initially 1, or 10^{0}).
- X/C Scale: homeopathic potencies; 1X is 10-fold and 1C is 100-fold dilution (initially 0X, 0C).

******Around here is a good point for splitting the activity into two days******

After the upper data table is complete, briefly discuss the values and patterns it contains, making particular note of the X and C scale values (e.g. 4X and 2C for cylinder #4.) Next fill out the lower data table, which are hypothetical cylinders as though the dilution experiment were continuing. Recognizing patterns in the data makes this process very reasonable. Keep in mind that the dye molecule number will reach ~1 at cylinder #20, and so any higher cylinders are increasingly unlikely to have any dye left in them. *Especially* compare the C scale values on cylinders #60 and #400 with the entries in the dilution Wikipedia article- these are the most important connections because they represent actual claimed Homeopathic remedy potencies. It's best to discover the dilution analogies for yourself, so *BE SURE* to read about them in the article!

After concluding that Homeopathy indeed qualifies as Pseudoscience (explicitly due to conditions A and C from before), fill out the remaining questions and move onto students sharing with the class their chosen "Discussion Piece" portion of the worksheet. The first iteration of this lesson allocated around one-quarter of the time to this student participation, and given the resounding interest this may have been too conservative! To clarify, "pseudoscience" in this context includes things like conspiracy theories, hoaxes, urban legends, etc. This greatly expands the potential choices for students, and helps keep the discussion more varied and lively than hard-science topics alone might allow (though those are also interesting.) Allow for an open discussion with the instructor offering examples if students are apprehensive sharing their own. For each topic shared, have the contributing student/instructor describe it a bit and explain what classifies it as pseudoscience (recall the three conditions stated earlier.) Above all, be flexible and enjoy some of the wild ideas that get thrown around!

Rough timing for the entire lesson is a 25% split for each of the following points:

- Session 1
  - Introduction to Pseudoscience and Homeopathy; Beginning the experiment.
  - Finishing the experiment; Filling in the upper data table.
- Session 2
  - Recap; Filling in the lower data table; Analogies/thoughts on Homeopathy.
  - Sharing/discussing additional pseudoscience topics; Wrap-up.

Assessment

- Survey students for comprehension of "pseudoscience" and "homeopathy" terms.
- Ask groups to explain their methodology when conducting the dilution experiment.
- Survey students about constructing the data table and providing analogy examples.
- Ask students to share their reasons for classifying additional topics as Pseudoscience.

Additional Information

For advanced students or a High School applicable lesson, stress the quantitative aspect of the experiment by having groups formulate their own needed approximations. Details concerning these approximations are found in the "Extra Info" guide and can be adjusted to require more critical thinking from students (especially if they are familiar with moles from chemistry.) Also, emphasis on fewer but more detailed examples during the concluding discussion may benefit higher-level students. The remaining portions of the lesson are largely grade-independent and can be performed similarly as stated in the plan.