Column Editors:
Janelle M. Bailey, Temple University, Philadelphia, PA; TPTAstroNotes@gmail.com
Shannon D. Willoughby, Montana State University, Bozeman, MT

Busting misconceptions through modeling

Lawrence Krumenaker, University of Cologne, Cologne, Germany (retired); larryk@hermograph.com

There are numerous misconceptions about how the world—and universe—work, often brought about because common everyday experiences are at scales at which the laws of science aren't blatantly obvious. For example, the world appears flat because human experience only sees so few miles in the distance of Earth's curvature is not evident. Stars appear to move in the sky because we humans don't feel the rotational movement of the Earth we live on. These misconceptions exist in the general public, students, and even teachers of all levels.[1,2]

There are numerous articles in the scholarly literature about what misconceptions abound, in all sciences but notably in astronomy and physics.[3,4] What really makes reality real and changes misconceptions is reproducing the various scenarios, observing factually which ones actually produce the effects we see. This was the substance of a graduate-level course for teachers the author ran at the University of Cologne, Germany, in the Physics Didactics Department. (Some non-course workshops with both teachers and teacher trainees were also done in Italy, Canada, and several US states.)

The key to the process is to first identify common misconceptions for a particular topic, and then set up situations to test those misconceptions and the scientifically accepted explanation **using the same celestial or terrestrial objects (most often using various models and everyday materials) for all the explanations**. The results provide the "proof" of which one is true and which one(s) is a misconception.

The first weekly classes of the German course had the professor demonstrate three misconception models. The first was climate and seasons and their cause. This was followed by the cause of Moon phases. The last was more physics related, rainbows. After those three lessons (discussed in detail below) were demonstrated, students in the German class, all graduate students—some already employed as teachers, some future teachers—picked a number of phenomena to study, in astronomy, chemistry, physics, and even biology (see box). Following one-on-one discussions with the professor for guidance, they tested their choice(s) out on each other in different class sessions, garnering constructive criticism and advice. The practiced and corrected strategies were then tried out on school groups that came to the university for "lab sessions" from neighboring German schools.

The "busting" process goes thusly:

First, the teacher needs to know in advance, through scholarly journal research, what misconceptions students are likely to hold and have enough of the particular model needs available in storage.

Some student misconception projects

- Flow of heat between objects or fluids
- Misconception concerning phase transition temperatures of water
- Sinking and swimming objects
- Gravity misconceptions, regarding needs to have gravity, which way it increases, and whether it works on a whole object or parts
- Spreading of sounds in solids, liquids, gases, and vacuum

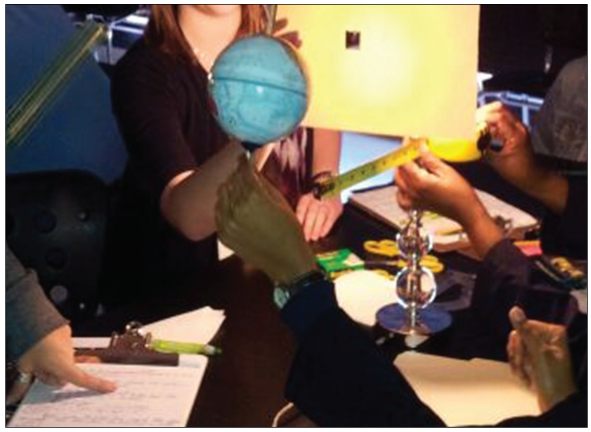

Fig. 1. Teachers preparing to measure the area of "sunlight" produced on a globe, with the Earth distance preset and pole orientation set for a season.

Second, properly framing the questions using age-appropriate content words, and not aiming the questions to get a desired true answer, students are asked about what causes a particular phenomenon. The answers can be provided with a drawing, a brief written statement, or some other communication method, as long as each student gives their answers independently without being influenced by answers shouted out, put on the board, or publicly stated.

Third, the teacher quickly makes a list of student responses, in no particular order, but with the number of suggestions given by students counted to see which ones are the most prevalent.

Fourth, students surmise how they might model the phenomenon—e.g., what items are needed and what variable(s) need(s) to be changed to test the different conceptions.

Fifth, the teacher gets out the appropriate materials—models and tools—and the students, in groups of four to six people, try out *all* the conceptions using their equipment: they make empirical observations, measurements, or both as the models require, and see which one conception accurately reflects real observations.

We will look at two misconceptions: first, climate and seasons. Is summer warmer because Earth is closer? Is it because

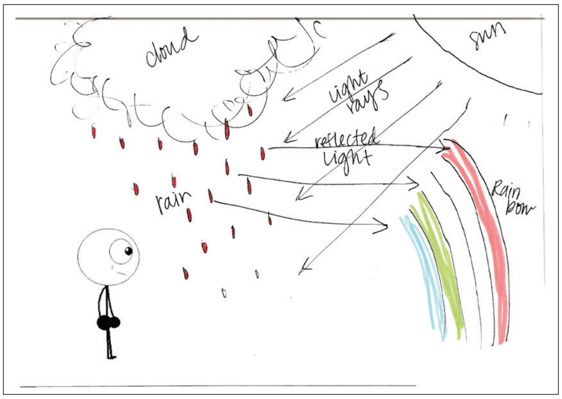

Fig. 2. A participant's prelab misconception regarding the cause of the rainbow.

Fig. 3. A glass raindrop, backed by reflective foil, duplicates a raindrop making a spectrum (rainbow) of the Sun through refraction and reflection.

of the angle at which the sunlight hits the different hemispheres, or is it just that the hemisphere where it is summer is closer to the Sun than the hemisphere where it is winter? A bright tungsten bulb acted as the Sun, or if possible, using the Sun itself, an Astronomical Unit (AU) distance scale was developed, and the distances were computed for the globe positioned at perihelion and aphelion (a 3% difference) on the scale. A large piece of cardboard with a 1- to 2-in. (~5-cm) square cut out allowed a square image of "sunlight" to be displayed on the globe surface, generally aimed for the location of the students (US, Germany, or Canada). It was always held at the same distance (student's choice) from the globe surface no matter how the globe was oriented (Fig. 1). Putting the globe with the proper tilt and direction of the North Pole for the winter and summer seasons, the students made measurements of the area of the sunlight square at winter and summer, and perihelion and aphelion, locations. Students were able to see that the largest square of sunlight, representing a lower heat flux density, occurred in the hemisphere tilted away from the Sun, vs. the smallest square where the globe tilts toward the Sun. Students also tested changing just the distance and not the tilt direction. Quantitative measures of area (winter/summer, near/far) showed that the tilt gave considerably larger differences than just distance changes alone. Thus, seasons and climate are a function of how much Earth tilts inward or outward from the Sun, not whether it is closer or farther.

For the last scenario listed above, a physics misconception often exists in explaining the rainbow. Every student and teacher has seen them, generally knowing they involve the Sun and raindrops, but where are all the constituents that produce rainbows that you, the observer, see? Teachers in workshops, or upper elementary students in real "lab classes," were given a piece of paper showing a stick figure person and asked to draw where the Sun and the rain were located (in front of, behind, above, etc.) compared to the student (observer), whether they themselves would be in the rain or not, and, finally, where the rainbow they observed would be (Fig. 2). The recorded options were counted and displayed on a board in the front of the room, and various combinations of rain, rainbow, student, and Sun positions were set to be tested (i.e., Sun behind, rain in front of the observer, rainbow in front of and above the observer, etc.). To model the variations, glass spheres filled with water represented raindrops, small bright lights represented beams of sunlight, and the teacher/student observer was placed in various positions. These were all tried until the rainbow (i.e., the spectrum of the light refracted and reflected in the glass sphere back to the observer) was seen (Fig. 3), thus allowing the students to see the necessary conditions for seeing rainbows and check them against different conceptions of how rainbows are made.

In reality, the student does not have to be *in* the rain, but the raindrops making the rainbow have to be in front of the student, and the Sun behind the student, and Sun, rain, and rainbow all at an angle above their eyes.

In conclusion, while any science class can't possibly cover all misconceptions and just telling a student what is correct and what isn't doesn't always "take," **modeling all the possibilities with the same model parts but in the different configurations found in the class survey** is an ideal way to unteach stubborn misconceptions about physical phenomena.

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