Challenge: Seeing Spatial Relationships in Three-Dimensional Physical Models

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Abstract

Earth Science teachers commonly use physical models. But, perhaps because of variations in spatial thinking skills, there may be gaps between what teachers understand and what students learn. Simple modifications can enhance the effectiveness of such models for helping students improve their spatial thinking. This article provides examples of how to incorporate models into instruction. One uses human figurines to improve the understanding Earth-Moon motions, and the other uses a string to expand the comprehension of Earth-Sun relationships.

(Note: This article is one in a series about spatial thinking in Earth Science education. The first, "Opening a Conversation about Spatial Thinking in Earth Science," appeared in The Earth Scientist, Winter 2012.)

The Challenge

Nearly all of us use physical models in our Earth Science classrooms. Think of models of molecules and mineral crystal lattices, landform models, stream tables, and models of the Sun-Earth and Sun-Earth-Moon systems. For students, very small, very large, very slow, and very fast processes can be made visible and more understandable through the use of such models.

Carefully-designed physical models go beyond mere descriptions of nature, to foster explanatory or predictive power. Physical models have broader relevance too: they aren’t just “toys for kids,” but are used by practicing geoscientists to study systems that can’t be manipulated in nature, such as divergent plate boundaries or accretionary wedges (Hickson, 2011.)

One of the reasons why physical models can be powerful learning tools is that they allow for manipulation and exploration of spatial relationships between objects in three-dimensional space. Students can see with their own eyes how spatial relationships change as the elements of the system are manipulated.

If you are an Earth Science instructor, your spatial thinking skills are probably stronger than those of many of your students. Simply because you can look at the model and “see” lunar phases; angle of insolation (incoming solar radiation); or other spatial relationships does not mean that your students can do so. How can you, as the instructor, make the key spatial relationships in the model more salient for your students?
For example, consider the use of spheres and light sources to develop student understanding of lunar phases and solar insolation. To imagine what the model Moon looks like from the model Earth requires a skill called perspective-taking: envisioning what something would look like from a vantage point that you are not now currently occupying. This is known to be a challenging perceptual and cognitive task for many humans. To grasp the impact of variation in angle of insolation requires envisioning and mentally quantifying an angle (between the surface of the earth and a ray of sunlight), another spatially-demanding challenge.

**Suggested Teaching Strategy: Use Figurines and String in Physical Models to Make the Invisible Visible**

We propose a couple of simple, powerful, inexpensive modifications to commonly-used physical models that make key spatial relationships more salient. The goals are two-fold: to help struggling students grasp important Earth Science concepts, and to enable students who already grasp the basics to embrace higher-order predictive and explanatory challenges.

The first model we'll consider is the “moon phase model.” This commonly involves two spheres and one light source; e.g., a basketball to represent the Earth and a tennis ball to represent the Moon. Light is shined toward the model Earth. The model Moon is moved around the model Earth in a roughly circular path and observed at different points in its ‘orbit.’

Here, we take inspiration from Jean Piaget’s classic “three mountains task”. (See Fig. 1.) In this test, a child is put in front of a model of three mountains. A doll or stuff animal is placed at another location. The child is asked to select a picture corresponding to how the mountains would appear from another vantage point. Children find it easier to envision, “What would the teddy bear see?” rather than answering an abstract question like “What would you see from position X?”

We suggest that when using the lunar phase model, you provide to the students, a humanoid figure - such as a toy figurine or clay person. Such figures are easy to purchase or make. Students would first affix the figure to the model Earth in the mid-latitudes of the northern hemisphere (Fig. 2). The use of this figure provides us with a concrete ‘observer,’ making perspective-taking more salient. Describing what the figurine would see may be easier for many students than trying to image what they would see if they were somehow on the globe. Students should be able to determine that the figure needs to face toward the model Moon, and that the Moon can only be seen when the Moon is on the same side of the Earth as the figure. Humanoid figures also have clearly defined left, and right sides. We can then more easily talk about whether the left or right side of the model Moon is illuminated, as seen from the figure’s perspective.

Considering the Moon’s appearance from the figure’s vantage point allows us to introduce more challenging pedagogy than we might otherwise use. Rather than telling your students which way the Moon revolves around the Earth, you can give them, or have them make, a lunar calendar. Then, using the model and the lunar calendar, they can figure out that only one of the two possible revolution directions (east-to-west versus west-to-east) shows to the northern hemisphere figurine the correct sequence of lunar phases. An enrichment challenge for more able students involves asking them to predict what the lunar phases would look like from the mid-latitudes in the southern...
hemisphere. If they think to position a second figure in the southern hemisphere, they have a better chance of succeeding on this challenging prediction task. They would then compare their prediction, with southern hemisphere data to confirm or refute their prediction.

The Earth-Sun system is the next physical model we'll consider, with a globe or sphere representing the Earth and a light source representing the Sun. Such models are often used to investigate variations in daily and seasonal insolation, day/night lengths, or impact of latitude on climate. Generally, the model Earth is made to rotate about an axis as it revolves in a roughly circular path around the model Sun. The plane of the model Earth’s revolution (the ecliptic) is typically parallel to the floor and the model Earth’s axis is tilted with respect to this ecliptic.

First, consider the day-night cycle. The day-night cycle is about changes in angle of insolation over time. If we watch a particular location on the model Earth's surface for an entire rotation, we observe variations in how directly the light from the model Sun is striking it. And for some period of time, the light is blocked by the bulk of the model Earth, representing “night”. When a point on the rotating model Earth is first illuminated, the light strikes it at a low angle, and the figurine placed on the globe would experience “sunrise”. During “morning” as the globe rotates, the angle of insolation increases until “solar noon” before decreasing again until the point is no longer illuminated, and the figure experiences “sunset.”

To increase student understanding, it is important that there be a shift from teacher-demonstration to student-exploration. The aim of using this model is for students to grasp the relationship between the angle of insolation and intensity of insolation, which relates to temperature. However, recognizing the angle of insolation at a location on the model at any moment may not be obvious to students. So we propose the use of a string to show the path of the light. One end of the string should be held near the light source. The other end of the string should be held near the surface of the model Earth at the location of interest (Fig. 3). The angle that the string makes with the model Earth's surface is a visual representation of the angle of insolation. This helps clarify and makes concrete the angle of insolation. Students can compare the observation of string angle with personal experiences of cooler temperatures in the morning and evening and warmer temperatures in midday.

Having established the use of the string to visualize angle of insolation, and the relationship between angle of insolation and daily temperature changes, we suggest next using our Sun-Earth-string model to explore the effect of latitude on climate. Here we are concerned with variations in angle of insolation across space rather than time. The tropics experience warmer climates than the poles because the sunlight is more direct in tropical regions. Our model shows larger angles of insolation near the equator and smaller angles of insolation near the poles, and the use of string representing the path of sunlight makes this relationship more obvious. Rather than having the teacher simply tell the students what causes the climate to vary from pole to equator to pole, students equipped with globe, light source, string, and an understanding of the day-night cycle may be able to discover...
this relationship themselves and begin to construct their own explanations of climate zones across the globe.

Finally, you or your students could use the Sun-Earth-string model for seasons. This requires simultaneously understanding variation in angle of insolation across both time and space. You can move the model Earth around the model Sun, maintaining the orientation of the axial tilt with respect to the model ecliptic. When you do this, you will see variations in the angle of insolation for a given location.

Consider a location in the mid-latitudes of the northern hemisphere. You would find the most vertically-incident light when the model Earth is positioned in such a way that the axis is tilted with the northern hemisphere pointing toward the model Sun (northern hemisphere summer). Conversely, you find the least vertical light when the model Earth is on the opposite side of the model Sun, so that the axis is tilted with the northern hemisphere pointing away from the model Sun (northern hemisphere winter). You can relate these to your experiences of warm summers and cool winters, respectively, and could again bring in real-life data. The use of the string, again, makes clearer the somewhat abstract concept of the angle of insolation.

Dynamic physical models are traditionally used in ways that foster kinesthetic and visual learning. But this does not fully leverage their power—physical models can also be used to provide students with opportunities to construct their own knowledge when you ask students to use models to answer questions, rather than confirm teacher-given facts. Simple modification of commonly-used models, such as by the use of figurines or string, can make spatial thinking tasks easier and can allow students to take on higher-order tasks. These modifications also make models more comprehensible to students with weaker spatial-thinking abilities. We encourage you to think of additional modifications to these or other physical models.

References


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