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Model Limitations

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There's more to scientific models than meets the eye

Model Limitations

SPACE EXPLORATION HAS SPAWNED MORE interest in science among teachers and students than any other topic in recent science education history, and teachers can use space science as an opportunity to encourage students to observe and make new discoveries for themselves. Many times, however, we run into obstacles. One trend we have noticed is that students can form misunderstandings based on simplistic explanations such as catchy astronomy activities on the back of cereal boxes, cartoon renderings of life on the Moon, or linear models in textbooks depicting the Solar System. These misrepresentations of science present problems for instructors.

MISCONCEPTIONS

Student misconceptions about astronomy are well documented, and studies show that accepted scientific explanations usually are incompatible with students' common explanations of observable phenomena like seasons, eclipses, and the phases of the Moon (Whitley, 1995; McDermott, 1984). Many commonsense explanations seem appropriate but do not hold up to scientific standards. For example, despite their inappropriateness, models that explain eclipses are often used by students to demonstrate Moon phases or other phenomena. Even concepts as fundamental as the relative size of the Solar System take time and attention to acquire as one's own way of thinking.

Researchers have found that misconceptions and commonsense explanations are conceived early in life and color one's interpretation of phenomena throughout life (Ausubel, 1968; Trowbridge and McDermott, 1981). Because of this, preservice teachers have been found to maintain personal misconceptions about Earth and space science long after completing university physics and geology classes (Schoon, 1995). Our major concern is that erroneous commonsense interpretations of daily phenomena will go unchallenged throughout preservice teachers' content preparation and will be passed on to their students.

Preservice educators have few experiences that directly challenge their commonsense notions or cause them to reflect on the nature of scientific knowledge. It is generally agreed that in order to combat misrepresentations, science lessons must be heavily steeped in authentic experiences. It is a goal in our preservice and inservice programs that teachers learn to plan lessons that connect real scientific activities to the experiences and the lives of students. We wanted to find out how students learn and how teachers plan lessons, and one of our goals was to critique the resources that students and teachers use to form astronomical concepts.

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MODELED INADEQUACY

We began by examining the back of a cereal box that listed astronomical facts, illustrated by pictures of the planets. Consumers were encouraged to build a model of the Solar System by cutting out the images and placing them on a clothes hanger. (The astute reader will recognize the impossibility of using two-dimensional pictures to build a scale model of the Solar System on a clothes hanger.) We asked a group of preservice and inservice teachers to draw a model of the Solar System and to critique the models offered by their peers. Participants worked in small groups and shared their prior knowledge of the Solar System.

Two different types of models emerged. One model analogous to a football field's gridiron displayed the planets in a linear row. The other model was a typical, textbook-type, orbital model. Most models presented by our preservice teachers paid little attention to the ratio between a planet's diameter and its distance to the Sun.

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A follow-up discussion focused on what participants felt was "scientific" about their model and the cereal box activity. One participant became aware that she misrepresented sizes and distances when teaching astronomy to elementary students. She realized that for more than five years she had dealt only with the comparison of linear distances. "Our sixth grade science curriculum includes a study of the Solar System. Many activities are available for me to use in instruction, so I selected a few to demonstrate knowledge about the Solar System. Now I am taking an astronomy class, which helps me reflect on ways I can improve my teaching. I can clearly see how an inquiry approach to investigating the Solar System opens the door for students' questions. Most importantly, I have become aware of the limitations of linear models."

When participants in this study reflected on the limitations of their models, most did not see the incongruencies in their models until the instructor pointed them out. Thus, it became apparent that shortcomings of participants' models of the Solar System were not adequately addressed through independent peer coaching, although participants did learn to be skeptical of their prior experiences and text authorities.

STEPPING OUT OF FLATLAND

To make models of the Solar System, participants used the Internet to find NASA's measurements of the planets' sizes and distances from the Sun. Participants were then instructed to use anything in the room (adding machine tape, pencils, balls, and so forth) to demonstrate proportional solar distances and planetary diameters. Students made calculations on paper before trying to build physical models of the Solar System. Shortly into the activity students asked questions like, "How are we supposed to do this? We don't see how our model can fit both the distance and diameter measurements with the same scale! On our scale, a pencil represents a distance of more than 1000 kilometers!"

Some students thought it futile to continue because they were unable to reconcile the differences in magnitudes of both measurements. Others insisted that they needed only to make their models bigger. We offered them the opportunity to complete the project outdoors. In doing so, students got a far better idea of the sizes of planets and their distances from the Sun—they could not even see the less-than-1-millimeter depiction of Pluto when they were standing where the Sun was on their 100-meter scale model of the Solar System. Attempting to build a three-dimensional model of the Solar System dramatically showed participants how vast our Solar System is and how misleading a simple linear model can be.

Participants became keenly aware of the limitations of their models though they were not yet able to replace their commonsense notions with expert ones. Subsequent discussions focused on reasons for changing simplistic representations despite their rational or pedagogical usefulness for teaching scientific concepts. It was clear that asking teachers to develop a working model of an abstract concept like a heliocentric model of the Solar System was difficult for them but led to greater understanding of the nature of science teaching and learning.

GOOD SCIENCE EXPLAINS OUR UNIVERSE

Despite discussing the limitations of models, participants' comments showed that they did not grasp the comparative orders of magnitude of their data. Not only did they struggle with the understanding of implicit scientific concepts and models but they also struggled with the messages about teaching and learning implicit in this type of instruction. These persistent misunderstandings were brought to the attention of the instructor through interactions like the following:

Group leader: Does your model explain why there is no such thing as a Venetian or Jovian eclipse on Earth?
Participant: No, not really. I know my model does not have an accurate ratio of the diameter of Jupiter to its distance from the Sun, but all I need to do is stretch it out, you know? I'd make my model longer and bigger, right?
Group leader: Okay, so if you make the model longer to represent both length and size, then where is Pluto on your model? And how big would it be on your model? Okay? So that would be here to (a local city 70 kilometers away). Would you be able to see a ball that represents Pluto from where you are standing now?
Participant: No.
Group leader: So what does that tell you about the usefulness of your model to teach students about the relative distances and sizes of planets? Can you really just make your model bigger to make it a useful teaching tool?

We have yet to find a model that adequately describes the Solar System. This is a property we find implicit in most models (for example, Bohr-Rutherford models of the atom) and, in fact, explaining this inadequacy was a specific objective we sought to teach our students. All scientific models have implicit imperfections, especially if used broadly in a number of teaching contexts.

The discussion of size and dimension sets the stage for reviewing the explanatory power of scientific concepts. Scientific ideas maintain their longevity when they explain events or are closely connected to others that do. To help participants grasp this kind of explanatory power, we posed questions to our preservice and inservice teachers that required them to explain events they had all witnessed using their newly acquired knowledge and models. These events included the existence of lunar eclipses but the absence of Venetian and Martian eclipses. Because these events can only be explained using a three-dimensional model and correct proportional relationships, they are good barometers for the utility of each model in explaining broad sets of phenomena—a fundamental tenet of any worthy scientific concept. One participant explained that only through the construction and use of a three-dimensional model could she derive a useful and more complex understanding of the Solar System.

The ultimate goal for these teachers was understanding the predictive powers of their models and of any authoritative scientific explanation. When real data about distant planets, stars, and galaxies is used to construct knowledge (which in turn encourages predictions and explanations of observable events) teachers and students have moved toward this goal.

CEREAL BOX SCIENCE

Recent science education reform requires that teachers do more than address student misconceptions. Teachers must assist students in learning how to acquire knowledge and how to be critical of knowledge claims. Examining the pedagogical limits of a cereal box activity is just one way of addressing some of these challenges.

We do, however, have three major reservations about gearing instruction toward potential student misconceptions. First, teaching becomes an unmanageable task when success is based on changing the individual conceptions of all students. Second, gauging instruction may be a difficult task because students' commonsense notions about their experiences may not match up well to the goals of instruction. Students talk differently about the world than scientists do, and it takes an accomplished teacher to recognize the science in the talk of the students. Finally, student misconceptions are just one problem science teachers face, and guiding instruction toward this one concept-oriented goal may compromise other aspects of teaching.

We found that this experience helped preservice and inservice teachers to critically examine their favorite lessons—ones they previously thought were effective for teaching scientific concepts. In order to significantly affect teachers' practices, change must occur on two levels. On one level novice teachers need experience and assistance using scientific concepts and models. A prime example of this was our teachers' inability to address or recognize the most basic application of celestial models. Experts say science students cannot simply acquire correct concepts but must construct models and test hypotheses to understand scientific concepts that explain the world (McDermott, 1984; Driver et al, 1994).

On a second level we know that excellent teachers understand science as something other than an activity to acquire facts or the blind use of manipulatives. Teachers without experience are left to choose or design activities on their own. The cereal box activity mentioned previously served as a venue for us to critique teachers' favorite activities and to uncover teachers' reasons for holding tightly onto certain lessons. We were able to evaluate activities and models for their scientific merit and not simply because they were catchy, colorful, or inspiring.

If teachers believe that science is a list of facts to be memorized and that scientific theories can only be tested by scientists, they will have no tools for answering their own questions, answering students' questions that are outside their received knowledge, or making sense of scientific claims that may change. Clearly, we must all plot a course in our classrooms to examine alternative concepts so we are more than "cereal box" teachers. ✧

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