The Science Representation Continuum

From concrete to abstract, finding the right balance of science representations is key to lasting understandings for students.

By Joanne K. Olson

Research indicates that people more easily understand abstractions when they are preceded by concrete representations (Lawson 2002). This is why we encourage young readers to look at the cover of a book and the illustrations prior to working through the textual representation. This is also why we use manipulatives in mathematics prior to the introduction of symbolic representations such as numerals. The same principle applies to effective science instruction. The spectrum below illustrates some commonly used representation types and their level of abstraction along a continuum (Figure 1).

Real objects are the most concrete representation type. Research-based science teaching models such as the learning cycle or 5E model (Lawson 2002; Moyer, Hackett, and Everett 2007) begin instruction toward the left side of the spectrum by having students experience the phenomenon being studied or use a hands-on activity that closely models an aspect of the concept. Following such experiences, the teacher draws out students’ initial sense-making and introduces relevant concepts that students cannot come to on their own. This can be accomplished in many ways, using drawings, photos, text, tables, or other representations. Students then work with the concept through application by re-representing concepts either through a new hands-on experience or another representation.

This “experience first” method of teaching matches how people learn, and thus not surprisingly, it also models how scientists develop scientific knowledge (Feynman and Leighton 1997). Scientists do not begin with vocabulary words and try to figure out where to apply them in nature. Instead, they begin with a puzzling phenomenon that they attempt to explain. Terminology is developed when the scientist has a need for those terms, and that occurs when the

Figure 1.

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>real objects</td>
<td>video</td>
</tr>
<tr>
<td>photos</td>
<td>drawings/diagrams</td>
</tr>
<tr>
<td>graphs</td>
<td>tables</td>
</tr>
<tr>
<td>formulas</td>
<td>text</td>
</tr>
</tbody>
</table>

(Modified from Pozzer and Roth 2003)
Ideas and techniques to enhance your science teaching

Figure 2.

Sample Scaffolding for force and motion.

The following example is one way such an instructional sequence might be developed.

**Day One:** Give students a variety of cars, each with a different mass and a long wood ramp. Give them a challenge question: “What car, if rolled down the ramp, will push the block farthest? How might you test your idea?” Have students share their findings afterward. Raise the issue of how high their ramp was placed, because groups will likely have selected different heights. “How could we get the car with the least mass to move the block the same distance that the car with the most mass moved it? Try out your ideas and see what you find.”

**Day Two:** Ask students to share their results and initial ideas from the day before. “How do we know what cars moved the block the farthest? What height maximized the distance the block moved? I’m going to give you some butcher paper, and I want you to place it on the ground underneath the end of your ramp. Then, you can draw on the paper where the block ended when you tested each car. What other information will we need to record on this paper?” Have students work on this problem and decide on a plan before they begin. Have multiple colors of crayons available to record data (red could be for the lowest distance, blue for the next, etc.). Display students’ paper when they finish, and have groups share results. “Let’s think about the relationship between the mass of the car and the force it put on the block. What could we say about this? When the mass of the car is greater, it _______. Now, as a small group, write a similar sentence for the acceleration of the car and what it does.”

**Day Three:** Revisit students’ summary statements the previous day. Add the following new challenge. “Here is a new car. Use your original cars to predict what effect this new car will have on the block. Be as accurate as you can without actually running this new car down the ramp. You can use any of the materials available on the counter to help you with this challenge.” Have available rulers, a balance, the same cars and ramps as the day before. In this challenge, students more closely examine the distances the block traveled from the masses of the original cars, and use this knowledge to predict what the more massive car will do. This applies their understanding of the relationship between mass, acceleration, and force. The representations move from 1) a physical representation to 2) a visual diagram, to 3) a written sentence (text), and 4) back to their diagrams (and perhaps even taking measurements and creating a data table), and 5) finally back to the original concrete objects. This scaffolding from concrete toward abstract and back to concrete is important to help students understand and apply new ideas.

Consider the concept “the motion of an object can be described by its position, direction of motion, and speed” and that “unbalanced forces will cause changes in the speed or direction of an object’s motion,” which is a targeted learning objective for students in grades 5–8 (NRC 1996, p. 164). Many representations are available to convey this concept, including a computer simulation that models objects of varying masses colliding, the formula $F=ma$, force diagrams, toy cars of varying masses with drawings of where their collisions began and ended, a video that illustrates collisions, a children’s literature book that discusses moving objects, or a combination of these—and in many different orders. The most concrete representation on this list is the toy cars, and teachers comfortable using a learning cycle approach may likely choose that item as their first choice to represent the concept.
Once a concrete representation and an activity that uses that representation is selected, we then need to determine how well the activity represents the phenomenon. This is difficult because not all hands-on activities are of equal quality, and students are unlikely to develop accurate science ideas from experience alone. For example, having students roll toy cars without specific guidance is insufficient for them to develop an understanding of the concept. Similarly, a “cookbook”-style activity where students use the cars but are primarily focused on following directions may detract from the development of conceptual understanding.

The purpose of an activity is to serve as a concrete experience base that students can use to make sense of the more abstract science concept when it is later introduced and developed. The key is to select an activity that is as concrete as possible that provides students with experiences with the phenomenon. It is important that the experience is unspoiled by confusing distractions so that students will focus on important aspects we want them to see. Then the teacher can use this experience to help them understand the big science ideas and relationships.

In the force and motion example, students need to work with objects of the same mass going different speeds so they can see their effect on an object. Students can use other cars that have a different mass or increase the mass of the original cars by adding washers. One activity, however, is likely insufficient to help solidify ideas. Effective science teaching builds toward other representations so that students see multiple ways to represent phenomena. One activity is likely insufficient to help solidify ideas. Effective science teaching builds toward other representations so that students see multiple ways to represent phenomena. One way to scaffold instruction is to begin at one end of the spectrum (concrete), then use something more abstract (but still within students' developmental readiness), and then return to concrete representations to determine that the students understand the more abstract generalizations—the patterns and concepts we expect them to learn. Figure 2 (p. 53) describes a force and motion activity using toy cars scaffolded in such a manner.

However, it is important to remember that just because an activity is “hands-on,” it is not automatically an appropriate representation for students. For example, if we are teaching about volcanoes, ideally students could go on a field trip to observe the real phenomenon. But since this isn’t possible in most schools, many teachers prefer to use a papier-mâché volcano that involves baking soda and vinegar. Unfortunately, this hands-on model operates on a chemical process, lacks the production of heat, and produces a gas and a liquid that are quite dissimilar from the actual process of a real volcano. In such instances, using a representation that is as concrete as possible but creates fewer misconceptions is more appropriate than the papier-mâché model. For example, a video that shows footage of a variety of volcanoes is a better option to begin teaching this concept.

And, what if the content doesn’t lend itself to hands-on experience? This issue’s theme, Astronomy, is a challenging subject to teach because many of the phenomena are visible only at night, require specialized equipment to directly observe, and involve significant abstractions due to extensive time.
and distances. The key to helping students understand such topics is to first determine what concepts are beyond the readiness of young students to understand. In early elementary grades, concepts taught tend to be those that are directly observable. For young children, an object viewed through a telescope might be perceived as being located within the telescope! Understanding large spans of time and distance can be a struggle even for high school students. The key is to monitor students’ thinking and reasoning carefully so that concepts taught do not require abstractions that they cannot yet do (such as visualizing atoms, understanding a light-year, etc.).

At younger grades, focusing on observable phenomena is better conceptualized than abstract ideas. The next task is to determine what representation can begin the unit that will help students visualize as well as possible the phenomenon being studied. When teaching about causes of day and night, requiring students to observe the apparent motion of the Sun throughout the day and across several weeks will help students document shadows and develop drawings, charts, and text-based explanations for their observations. Those important patterns can be visualized prior to the introduction of the Earth/Moon/Sun system through the use of tennis ball models. When teaching causes of Moon phases, watching the Moon over a month in relation to the Sun’s position, and making attempts to explain this pattern is important prior to working with classroom models of the Earth, Moon, and Sun. After real experiences outside and work with models in the classroom, students can generate drawings and other representations that illustrate their developing understanding. Additional representations available include computer simulations such as “Starry Night” software or “Google Earth” to visualize perspectives that are difficult to model in the classroom. While computer simulations are not a substitute for the real phenomenon, they can be helpful when the real phenomenon cannot be directly observed.

**Summing Up**

Choosing representations is important for helping students to understand science concepts. Representations that are clear, accurate, and focus students’ attention to the phenomenon being studied help students to construct more accurate ideas. In addition, the order in which we use representations also impacts student learning, and beginning with concrete representations prior to the use of abstractions is more likely to result in accurate understanding of abstract concepts.

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**Connecting to the Standards**

This article relates to the following *National Science Education Standards* (NRC 1996).

**Content Standards**

**Standard A: Science as Inquiry**

- Abilities necessary to do scientific inquiry (K–8)
- Understandings about scientific inquiry (K–8)

**Standard B: Physical Science**

- Motions and forces (5–8)

**References**


