TARGETING SCIENCE MISCONCEPTIONS
IN MIDDLE SCHOOL STUDENTS:
What the Research Tells Us
INTRODUCTION

WHAT CAUSES THE CHANGE IN SEASONS?

Studies have shown that as many as 95% of people—including most college graduates—incorrectly believe that the seasons result from the Earth moving closer to or farther from the Sun.¹ In reality, the answer lies in the tilt of the Earth’s rotational axis away or toward the Sun as the Earth travels through its year-long orbit. Distance plays no role since the Earth actually is closest to the Sun during the first week of January!

Data from a 2011 examination administered by the U.S. Department of Education indicated that approximately two out of every three eighth-graders lack basic scientific knowledge.² The Science Assessment conducted by the American Association for the Advancement of Science (AAAS) revealed that students in grades 6–8 showed evidence of misconceptions at a surprisingly high rate of frequency, ranging, for example, from 31% for “Plants do not compete for resources” to 53% for “Molecules from food are not stored in the bulbs of plants.”

Concepts can be defined as ideas, objects, or events that help individuals understand the world around them.³ Conversely, misconceptions can be described as ideas that provide an incorrect understanding of such ideas, objects, or events that are not in agreement with our current understanding of natural science. Misconceptions can occur in students’ understanding of scientific methods as well as in their organization of scientific knowledge.

This white paper takes a closer look at the science misconceptions that students commonly have and the factors that shape these ideas. It draws from research to document for teachers the importance of understanding misconceptions as a first step toward addressing them in instructional settings. Finally, the document explores research suggesting that an inquiry approach to drive conceptual change—the instructional framework of Britannica’s Pathways: Science—can be effectively used to transform students’ misconceptions into true understanding.

Students typically bring a variety of misconceptions to the science classroom. According to the National Research Council (NRC), students in grades 5–8 are taught that energy is an important property of substances and that most change involves energy transfer. However, heat is a topic about which students typically have many misconceptions.

**FOR EXAMPLE:**

<table>
<thead>
<tr>
<th>STUDENTS MAY THINK…</th>
<th>INSTEAD OF THINKING…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature is a property of a particular material or object.</td>
<td>Temperature is not a property of materials or objects. Objects exposed to the same ambient conditions will have the same temperature.</td>
</tr>
<tr>
<td>Heat and cold are different.</td>
<td>Cold is the absence of heat. Heat and cold can be thought of as opposite ends of a continuum.</td>
</tr>
<tr>
<td>Cold is transferred from one object to another.</td>
<td>Heat moves from the warmer object to the cooler object.</td>
</tr>
<tr>
<td>Objects that keep things warm, such as sweaters, mittens, blankets, are sources of heat.</td>
<td>Objects keep things warm by trapping heat.</td>
</tr>
<tr>
<td>Some substances, such as flour, sugar, or air, cannot heat up.</td>
<td>All substances heat up, although some gain heat more easily than others.</td>
</tr>
<tr>
<td>Objects that readily become warm (conductors of heat) do not readily become cold.</td>
<td>Conductors gain and lose heat easily.</td>
</tr>
</tbody>
</table>


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In life science the NRC indicates that “Middle school students should progress from studying life science from the point of view of individual organisms to recognizing patterns in ecosystems and the ways they interact with each other and with their environment.” Yet, misconceptions abound in this area as well:

### STUDENTS MAY THINK…

<table>
<thead>
<tr>
<th>Concept</th>
<th>INSTEAD OF THINKING…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisms higher in a food chain eat everything that is lower in the food chain.</td>
<td>Organisms higher in a food chain eat, some, but not necessarily all, of the organisms below them in the food chain.</td>
</tr>
<tr>
<td>Carnivores have more energy or power than herbivores do.</td>
<td>While some carnivores may be larger and require more food than some herbivores, they do not have more energy or power.</td>
</tr>
<tr>
<td>Food chains involve predator and prey, but not producers.</td>
<td>Producers are an essential part of all food chains and webs.</td>
</tr>
<tr>
<td>The relative sizes of predator and prey populations have no bearing on the size of the other.</td>
<td>The sizes of predator and prey populations influence each other.</td>
</tr>
<tr>
<td>Varying the population size of a species may not affect an ecosystem because some organisms are not important.</td>
<td>All organisms are important within an ecosystem. Varying a species’ population size may not affect all other species equally, but it will affect the ecosystem as a whole.</td>
</tr>
<tr>
<td>Species coexist in ecosystems because of their compatible needs and behaviors; they need to get along.</td>
<td>Within an ecosystem, species compete for resources and feed on one another. Species live in the same ecosystem because of similar adaptations and environmental needs.</td>
</tr>
<tr>
<td>Traits are developed by individuals in response to the needs of the individual.</td>
<td>Traits are developed across generations in response to environmental demands.</td>
</tr>
</tbody>
</table>

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Although the term “misconception” simply means an idea or explanation that differs from an accepted scientific concept, students’ misconceptions can be quite complex. Students come to school with established knowledge about the physical, biological, and social worlds based upon their own ideas and explanations that may or may not be correct. Some misconceptions may change as students develop their ability to think abstractly, while others persist well into adulthood.

Students’ prior experiences profoundly affect their willingness or ability to accept other, more scientifically grounded, explanations of how the world works, particularly if this new information does not fit their established pattern of thinking. Rather, they refashion or modify the new information to fit the existing schema. Misconceptions are unknowingly created and reinforced as the learner builds explanations, unravels problems, and files new data based on faulty reasoning. The longer a misconception remains unchallenged, the more likely it is to become entrenched and resistant to change.6

**OTHER COMMON SCIENCE MISCONCEPTIONS**

- Objects float in water because they are lighter than water.
- The bubbles in boiling water contain air, oxygen, or nothing, rather than water vapor.
- Seasons are caused by the Earth’s distance from the Sun.
- Dinosaurs, humans, and cavemen lived at the same time.
- The terms “energy” and “force” have the same meaning.
- Batteries have electricity inside them.
- The Moon does not rotate on its axis as it revolves around the Earth.


In its 1997 publication *Misconceptions as Barriers to Understanding Science*, *Science Teaching Reconsidered: A Handbook*, the National Academy of Sciences suggests a process for breaking down misconceptions. The process requires teachers to identify students’ inaccurate beliefs, provide a forum for them to confront their beliefs, and then help students reconstruct their knowledge.

How can teachers go about ascertaining their students’ misconceptions? Asking probing questions combined with peer discussions can be instrumental in uncovering and clarifying what students really think. Teachers also must understand how students put pieces of information together to facilitate their learning.

One study found that teachers need to understand both the content they are trying to convey and the specific misconceptions students have in order to improve science instruction. The study, conducted at the Harvard-Smithsonian Center for Astrophysics, enlisted 181 middle school physical science teachers to take a multiple-choice test of conceptual knowledge, as well as administer the same test to 10,000 of their students. Twelve of the 20 test items were designed to have a wrong answer corresponding to a commonly held misconception.

Teachers who took the test were asked to identify both the correct answer for each item as well as the one that they believed students were most likely to select incorrectly. Although the teachers overall did well in selecting the correct answer, the results were more mixed in predicting students’ incorrect responses. Those teachers who were better able to predict their students’ wrong answers helped students learn the most. As American humorist-philosopher Will Rogers observed, “It ain’t what they don’t know that gives them trouble; it’s what they know that ain’t so.”

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Bringing About Conceptual Change

The process of replacing a misconception with a scientifically acceptable concept is called conceptual change. As pointed out previously, simply presenting a new concept or telling learners that their views are inaccurate will not produce conceptual change. Rather, learners must take an active role in reorganizing their knowledge, the characteristic that distinguishes conceptual change from other types of learning. The process of changing or replacing an existing conception produces a new framework that students can then use to solve problems, explain phenomena, and function in their world.

In her paper Teaching to Promote Deep Understanding and Instigate Conceptual Change (2006), Esther L. Zirbel stipulates four conditions that must be present to catalyze conceptual change:

**Dissatisfaction.** Learners must first realize that there are some inconsistencies in their current understanding and that their way of thinking does not solve the problem at hand.

**Intelligibility.** The concept should not only make sense, but the learners should also be able to craft an argument and ideally be able to explain that concept to other classmates.

**Plausibility.** The new concept must make more sense than the old concept and have the capacity to solve the problem better.

**Fruitfulness.** The new concept should do more than merely solve the problem at hand. It should also open up new areas of inquiry.

Strategies for helping students overcome their misconceptions are based on research about how we learn. For example, using methods that de-emphasize cookbook-like activities in favor of open-ended, inquiry-oriented investigations can engage students in discussions of scientific ideas in cooperative group work. Individuals who are asked to predict the results of their experiments are more willing to change their thinking than those who function as passive observers. Creating opportunities for students to confront their own beliefs should enable them to resolve any conflicts between their ideas and what they experience in a laboratory activity and/or discussion. Teachers also need to ensure that connections are made in a relevant manner between the concepts learned in the classroom and students’ everyday lives.

Zirbel suggests that to form new concepts or change inadequate ones, students have to be led through several processes, starting with consciously noticing and understanding what the problem is. Upon assimilating more information and evaluating it against prior beliefs, students have to work toward obtaining fluency in the newly acquired and understood concept.
BRINGING ABOUT CONCEPTUAL CHANGE (cont’d)

There are a number of models and strategies for driving conceptual change. Many models all share a structure similar to the conceptual change teaching strategy originally proposed in 1982 by Nussbaum and Novick⁹ below:

1. **REVEAL STUDENT PRECONCEPTIONS.**
   The first and most significant step in teaching for conceptual change is to make students aware of their own ideas about a topic or phenomenon.

2. **PRESENT AN EXPOSING EVENT.**
   Instruction begins with any situation that requires students to use their existing conceptions to interpret or explain an event.

3. **ASK STUDENTS TO DESCRIBE OR REPRESENT THEIR CONCEPTIONS.**
   The goal of this step is to help students begin to clarify their own ideas and understanding about a concept. Students can write descriptions, draw illustrations, create physical models, draw concept maps, design Web pages, or use any combination of these to make their conceptions explicit.

4. **DISCUSS AND EVALUATE CONCEPTIONS.**
   In this step, students clarify and revise their original conceptions through group and whole-class discussions. The teacher leads the class in evaluating each for intelligibility, plausibility, and fruitfulness in relation to the exposing event. Students with differing conceptions can work in pairs or groups to evaluate each other’s ideas.

5. **CREATE CONCEPTUAL CONFLICT.**
   As students become aware of their own conceptions, they become dissatisfied with their own ideas and become more open to changing them.

6. **ENCOURAGE COGNITIVE ACCOMMODATION AND GUIDE CONCEPTUAL RESTRUCTURING.**
   Students reflect on and reconcile differences between their conceptions and the target theory.

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THE ROLE OF INQUIRY IN CONCEPTUAL CHANGE

To facilitate the process of conceptual change, teachers must encourage and engage students in real thinking. Shifting the focus from lecturer-centered teaching to student-centered thinking and learning occurs when inquiry is incorporated into the science classroom. Inquiry, defined as a seeking of truth, information, or knowledge by questioning, is a dynamic approach that involves exploring the world, asking questions, making discoveries, and rigorously testing those discoveries in search of new understanding.¹⁰

When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively transform their misconceptions into understanding by combining scientific knowledge with reasoning and thinking skills.

The following section illustrates how Britannica’s Pathways: Science incorporates the process of inquiry to drive conceptual change in middle school science students.

TARGETING MISCONCEPTIONS WITH PATHWAYS: SCIENCE

As discussed above, overcoming students’ misconceptions can be a challenging process for even the most proficient middle school science teachers. Students need the opportunity to confront and examine their own thinking, make their own predictions, and resolve any conflicts that arise through inquiry-based exploration. Britannica’s Pathways: Science is designed to help teachers initiate conversations with middle school students about what they are thinking and why, facilitate discussion, and coach students along the way to a more accurate conceptual understanding of the science concepts being studied.

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TARGETING MISCONCEPTIONS WITH PATHWAYS: SCIENCE (cont’d)

This three-step framework addresses the requirements of research-based models for conceptual change. Nearly 100 interactive lessons support curriculum standards across 10 science topics.

**1. PREDICT.** Confronted with an engaging question, students use their prior knowledge to formulate an explanation for an event or an idea about a concept.

**2. INVESTIGATE.** Using articles, images, and video accessible directly from Pathways: Science, students dig for evidence to support or contradict their predictions. Students’ notes are dynamically captured and can be saved in an interactive graphic organizer and retrieved as needed.

**3. CONCLUDE.** Students evaluate the evidence they found and compare it to their original ideas to determine which idea is correct and why the misconceptions are incorrect.

As a supplement to the existing curriculum, Pathways: Science enables teachers to create a thought-provoking yet non-threatening learning environment for overcoming misconceptions. It encourages students to recognize inconsistencies in their thinking based on evidence, arrive at new explanations that better address the science phenomena they are studying, and adopt new understanding, which motivates them to pursue additional areas of inquiry.

For further information about Pathways: Science or other online resources available from Britannica, contact:

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