MOVING AHEAD WITH ALTernATE CONCEPTIONs

by Aaron Isabelle, Rosemary Millham, and Thaïs da Cunha

An alternate conception, also referred to as a misconception, is a deeply ingrained, scientifically inappropriate idea about something in the physical or natural world. (Note: The term alternate conception is preferred and is used in this article because it conveys respect for learners’ prior knowledge and personal experiences.) From an early age, and prior to any formal science experience, children develop meanings of concepts used in science teaching—many contrary to scientific ideas. These scientifically inappropriate ideas are not always altered during science instruction, as they are sensible and coherent from a child’s point of view. Alternate conceptions can, however, interfere with new learning. If new learning is linked to these scientifically inappropriate ideas, it will also be flawed (Crockett 2004; Duschl 1990; Klammer 1998).
<table>
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<th>Alternate-conceptions inventory correlated with the Next Generation Science Standards (NGSS)</th>
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<td><strong>1.</strong> Dinosaurs and cavemen lived at the same time. (<em>Life/Earth</em>) NGSS standard MS-LS4: Biological Evolution: Unity and Diversity; disciplinary core idea LS4.A: Evidence of Common Ancestry and Diversity.</td>
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<tr>
<td><strong>2.</strong> All metals are attracted to a magnet. (<em>Physical</em>) NGSS standard MS-PS2: Motion and Stability: Forces and Interactions; disciplinary core idea PS2.B: Types of Interactions.</td>
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<td><strong>3.</strong> Whales and dolphins are fish. (<em>Life</em>) NGSS standard MS-LS1: From Molecules to Organisms: Structures and Processes; disciplinary core idea LS1.B: Growth and Development of Organisms.</td>
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<td><strong>5.</strong> The phases of the Moon are caused by the shadow of the Earth on the Moon. (<em>Earth/space</em>) NGSS standard MS-ESS1: Earth's Place in the Universe; disciplinary core ideas ESS1.A: The Universe and Its Stars; and ESS1.B: Earth and the Solar System.</td>
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<td><strong>6.</strong> The Sun orbits the Earth. (<em>Earth/space</em>) NGSS standard MS-ESS1: Earth's Place in the Universe; performance expectation MS-ESS1-1: Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.</td>
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<td><strong>7.</strong> The Moon and the Sun are about the same size. (<em>Earth/space</em>) NGSS standard MS-ESS1: Earth's Place in the Universe; performance expectation MS-ESS1-1: Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons; and performance expectation MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.</td>
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<td><strong>8.</strong> It is hot in the summer because we are closer to the Sun. (<em>Earth/space</em>) NGSS standard MS-ESS1: Earth's Place in the Universe; performance expectation MS-ESS1-1: Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.</td>
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<td><strong>9.</strong> The Sun disappears at night. (<em>Earth/space</em>) NGSS standard MS-ESS1: Earth's Place in the Universe; performance expectation MS-ESS1-1: Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.</td>
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<td><strong>10.</strong> The Sun is food for plants. (<em>Life</em>) NGSS standard MS-LS1: From Molecules to Organisms: Structure and Processes; performance expectation MS-LS1-6: Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms; disciplinary core idea LS1.C: Organization for Matter and Energy Flow in Organisms.</td>
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<tr>
<td><strong>11.</strong> Birds are mammals. (<em>Life</em>) NGSS standard MS-LS1: From Molecules to Organisms: Structures and Processes; disciplinary core idea LS1.B: Growth and Development of Organisms.</td>
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Alternate conceptions pose a challenge for science educators. Finding the particular foundation for an alternate conception is complex and sometimes elusive because these ideas derive from students’ lack of experiential knowledge, a conceptual or contextual misunderstanding, or even inaccuracies in science textbooks (King 2010). Whatever the source, alternate conceptions remain pervasive and persistent in students’ thinking and can be carried for decades until conceptual change occurs and new schemas develop.

Despite efforts by educators, policy makers, and scientists in creating the Next Generation Science Standards (NGSS) (NGSS Lead States 2013), National Standard Education Standards (NRC 1996), and Benchmarks for Science Literacy (AAAS 1993), students are still struggling with basic scientific conceptual understandings. Even with the creation of conceptual-map strands and the Atlas of Science Literacy (AAAS 2001, 2007) to scaffold concepts, the advancement of methods of instruction to reveal and remediate alternate conceptions (Keeley, Eberle, and Tugel 2007; Keeley and Harrington 2010; Keeley and Sneider 2012; Liggitt-Fox 1997; Marshall, Horton, and Smart 2009; Michael 2006; Michaels, Shouse, and Schweingruber 2007; Palmer 1995), and the development of misconception inventories (Operation Physics 1998; AAAS 2014; NRC 1996), students continue to harbor alternate conceptions.

The good news is that according to current research, alternate conceptions can be used as the “raw materials of learning.” Larkin (2012) states, “If student misconceptions are viewed as models with explanatory and predictive power themselves, teaching strategies that seek to test and revise these models may prove quite powerful” (p. 955). However, before any teaching/intervention strategy can be implemented, teachers must first strive to uncover or unearth students’ deeply ingrained alternate conceptions. This can be accomplished by probing students’ prior knowledge (Keeley, Eberle, and Tugel 2007; Keeley and Harrington 2010; Keeley and Sneider 2012).

Our group, composed of three middle school teachers (sixth, seventh, and eighth grade) and three science-teacher educators, decided that middle school science students would not only benefit from an assessment of their prior knowledge using a survey instrument but also from an analysis of their scientific perceptions. This decision stemmed from the teachers’ frustration with their students’ science misunderstandings over the years. We agreed that this analysis would provide the teachers with a constructive method for assessing student understandings and inform their classroom instruction through effective evidenced-based practices. This study describes the steps that we followed in developing an alternate-conceptions inventory and survey instrument for middle school students, as well as techniques used to assess and analyze students’ thinking. We provide examples to illustrate our findings and offer suggestions for developing intervention strategies to help mitigate students’ inappropriate scientific ideas.

Methodology

Creating an inventory of alternate conceptions

To create an inventory of alternate conceptions for our study, we first researched common alternate conceptions, especially those identified in earlier misconceptions research. Specifically, we referenced a website compiled by Operation Physics that provides a comprehensive listing of common alternate conceptions in science (Operation Physics 1998). We also made use of the documented alternate conceptions on the science assessment website developed by the American Association for the Advancement of Science (2014).

Our final inventory consisted of 11 alternate conceptions. The sources of the alternate-conceptions inventory were both formal (Operation Physics 1998; AAAS 2014) and informal/anecdotal (misconceptions were added to the inventory by the middle school teachers as a result of their direct experiences with middle school students). Most of the statements chosen focused on life- or Earth/space-science concepts because the main focus of most elementary curricula is a combination of these sciences. Therefore, we wanted to be certain that the middle school students...
had previous exposure to the science concepts in our survey from earlier grades. In sum, we knew that these particular statements represented big ideas in science that middle school students should have a solid understanding of as a result of science instruction in the elementary school grades (e.g., mammals, magnetism, photosynthesis, planetary motion). See Figure 1 for our alternate-conceptions inventory correlated with the NGSS.

**Crafting and administering the survey instrument**

In our survey assessment instrument, students were asked whether they agreed or disagreed with each alternate-conception statement and used a comment box to explain their thinking. This process provided two sets of data: (1) a set of agree-or-disagree responses and (2) a set of explanations for the responses (see Figure 2 for a snapshot of the survey assessment). Our primary interest was not in the statement response of agree or disagree, although these responses informed us about student understandings (or lack thereof). Our primary goal was to analyze students’ explanations for their responses. We wanted to determine the depth of students’ conceptual understanding, students’ ability to find the language necessary to explain a concept, and whether or not students understood what they thought they knew (and to what degree), either through a careful explanation or an accurate application of their understanding. The survey was administered anonymously (using Survey Monkey) to 86 ($N = 86$) middle school students at the beginning of the school year.

**Analysis**

**Analyzing students’ thinking: Part 1**

From an analysis of students’ explanations and reasoning, many alternate conceptions were identified that are not found in current research literature. Essentially, we identified alternate conceptions within the explanations that could be problematic during instruction (at the start of initial instruction about a concept) or in an attempt to teach a concept formally taught in a previous grade. Preconceptions that are inappropriate ideas...
in science are difficult for students to reconceptualize without breaking down those concepts and building them back up in meaningful and lasting ways (Keeley, Eberle, and Tugel 2007; Keeley and Harrington 2010; Keeley and Sneider 2012).

The survey data were analyzed according to the following procedures: (1) A science alternate-conceptions rubric was used to code the data (see Figure 3); (2) after students’ alternate conceptions were identified, we cross-checked their explanations with existing science-misconception inventories; and (3) the percentage of students who held alternate conceptions was determined by specifically focusing on common alternate conceptions across the grade levels.

For example, when analyzing students’ responses to the statement “Whales and dolphins are fish,” we found that the majority of the middle school students correctly responded that whales and dolphins are mammals (not fish); however, many of their explanations regarding this statement were problematic (see Figure 4). Although whales and dolphins breathe air using their lungs and do not have gills, there is an alternate conception among these middle school students regarding characteristics that set a mammal apart from other living things. Out of 86 students, 26 focused on “breathing air” as the primary characteristic of mammals. It is also interesting to note that all students who correctly explained that mammals give birth to live young, have hair, and produce milk did not mention breathing air through their lungs as a characteristic of mammals.

In another example, we focused on students’ ideas conveyed in their responses to the statement “Trees are not plants.” According to the research of Osborne and Freyberg (1994), a common alternate conception in the life sciences is that trees are not plants. Students reported that when a tree is small, it is a plant, but when it gets bigger, it ceases to be a plant. This is a well-documented alternate conception, especially among elementary school students. Although none of our middle school students reported this idea, alternate conceptions were conveyed (see Figure 5). Thirty percent of 86 middle school students conveyed scientific misunderstandings about differentiating plants from other living things. Many students focused on physical characteristics of plants such as roots, leaves, and stems rather than plants as producers. This alternate conception became evident when students’ personal classification systems regarding trees and plants were probed.

Analyzing students’ thinking: Part 2

Next we took a deeper look at students’ explanations conveyed in the survey data. Working with the middle school teachers, we brainstormed ideas and posed thought-provoking questions that assisted the teachers in planning intervention strategies. Once again, we focus on the statements “Whales and dolphins are fish” and “Trees are not plants” to illustrate our findings. For example, even though a majority of middle school students correctly responded that whales and
dolphins are not fish, several problematic ideas were evident in students’ explanations. For example, two common sixth-grade student explanations were “If a living thing needs to breathe air, it is a mammal” and “Whales and dolphins are not fish; they are mammals because they breathe air.” Does this infer that fish do not breathe air? How does a student come to know this? Also, how does a student come to understand that the act of breathing not only sets a mammal apart from nonmammals but also differentiates living versus nonliving things? A common seventh- and eighth-grade explanation was “Whales and dolphins are mammals, not fish, because they breathe air through their lungs and do not have gills.” Why are these seventh and eighth graders not able to make meaningful connections to key attributes of mammals (e.g., mammary glands, live birth, hair/fur)? What prior ideas or experiences might be blocking a genuine understanding about the concept of mammal? Specifically, out of 86 student responses, the terms milk, live young, and hair were only mentioned twice.

Teachers need to help students understand the key characteristics of mammals without simply memorizing a list of traits. Just as scientists classify the diversity of life into a variety of special categories (kingdom, phylum, class, order, etc.), students need to participate in similar meaningful classification activities. If students learn that Mammalia is the name of a very large class of animals that includes the smaller order Cetacea (whales, dolphins, and porpoises), a specific type of marine mammal, then students may be able to reconstruct a mental representation of how scientists classify these living things (see Resources for a classification diagram). This would also help to introduce and reinforce the use of scientific academic language.

In another example, a majority of the middle school students correctly reported that trees are plants; however, the conceptual misunderstandings in their explanations are tied to the concepts of photosynthesis and plants as producers. Why would a middle school student be unaware that the most important feature of a plant (whatever the form—coniferous or deciduous tree, shrub, household plant, etc.) is that it makes its own food? Only 8 out of 86 students used the term photosynthesis in their explanations (without providing any details about the process), and only 6 students mentioned that plants make their own food. Only 1 student gave
a nearly complete explanation, by stating, “Trees, like plants, photosynthesize by using carbon dioxide and water to make glucose which is a plant’s food.” However, this student did not make any reference to the Sun. In fact, none of the middle school students mentioned the Sun in their explanations. How is it possible for students to think about plants and not suggest the importance of the role of the Sun? How does a student come to view a plant or tree as simply a combination of roots, stems, and leaves? Is this due to the lack of academic language (Snow 2010), lack of complete knowledge of the process of photosynthesis, or lack of experience or active involvement in growing plants? Teachers should create more scientifically based activities that not only emphasize that plants (and trees) make their own food but include all of the elements of photosynthesis so students can “see” what is happening, see why it is happening, and be able to explain the process accurately and clearly. This can only occur if students are somehow made to successfully apply their understandings.

Implementing intervention strategies

After sharing and discussing students’ ideas with the middle school teachers and analyzing students’ thinking, we codeveloped a list of intervention strategies to address these scientifically inappropriate ideas. Each middle school teacher agreed to implement a strategy in the classroom to target the alternate conceptions. Specifically, the strategies were characterized by active explorations in combination with the use of the language of science. The teachers used authentic assessment tools, already part of their classroom assessment system, to monitor student learning (e.g., science notebook entries, probing/open-ended questions, verbal/written communication, and class discussion).

For example, for the survey statement “Whales and dolphins are fish,” the middle school teachers used the What’s a Mammal? activity on the Discovery Education website, which provides an exemplary exploration of mammals and their key characteristics (see Resources). To assist with the classification and identification of mammals, students also explored the Smithsonian’s North American Mammal website (see Resources). Students investigated the order Cetacea in the mammal “family tree” and then researched the characteristics of each living thing. In addition, the teachers reported that they found it helpful to focus on unique examples to compare mammal and nonmammal characteristics to emphasize key mammalian traits. For example, a duck-billed platypus lays eggs but is considered a mammal because it has fur and mammary glands. Conversely, about 70% of all shark species give birth to live young, but sharks have gills, are cold blooded, and have skeletons of cartilage (i.e., lower vertebrate). Therefore, they are classified as fish. The comparison of different groups of living things with similar and different traits can lead to better understandings as students work to discover why the groups are separate.
For the survey statement “Trees are not plants,” classroom teachers emphasized the critical role of plants as producers in the food chain. Students researched and sketched various food chains (and food webs) with an emphasis on producers, while stressing the importance of the Sun as the initial source of energy at the beginning of each food chain. Teachers then focused on the ability of leaves to conduct photosynthesis by asking two simple questions, “What is photosynthesis?” and “What does this word mean literally?” (i.e., photo = light; synthesis = combine or put together; photosynthesis = to put together with light). After a class discussion, students explored an animation to understand what the light from the Sun is “putting together” (see Photosynthesis link in Resources).

Other middle school teachers taught about plants as autotrophs. When exploring different ecosystems, they emphasized that plants are the basis of food chains; plants convert sunlight into chemical energy, and that energy sustains the animals around us. This was brought up again when students studied fossil fuels; they learned that fossil fuels come from the remains of plants and animals, and that energy is again converted (having originated from the Sun). Lastly, when teaching about cells, the teachers focused once again on the process of photosynthesis, allowing students to see how the atoms recombine to transform carbon dioxide and water into sugar in the presence of sunlight energy. Therefore, in the teaching of a single concept, teachers used multiple contexts: food chains/webs, ecosystems, fossil fuels, and plant cells. The use of academic language in this context was critical and helped to make an explicit connection between the process of photosynthesis and green plants (including trees).

(Note: We cannot claim that the intervention strategies used were effective in mitigating students’ alternate conceptions; this would require a different research design. However, we are confident that the intervention strategies were effective in fostering student understanding. The strategies were developed in response to evidence gathered from an analysis of students’ explanations, and the teachers reported an increase in students’ abilities to explain the science concepts more accurately.)

Conclusion
Evidence-based teaching and learning is essential to develop correct scientific understandings and help mediate alternate conceptions. Our findings point to specific needs to negotiate alternate conceptions. First and foremost, teachers and students need to use the academic language of science, which is critical when trying to teach scientific concepts (Snow 2010). The more students use scientific language, the better their understandings. Although using scientific terms can be daunting at the start, repetition in context greatly enhances students’ knowledge and their ability to apply what they know. Difficult science words become familiar with use, and students need to know what they mean and how to use them. In fact, understanding academic language early on can mitigate many alternate conceptions (Wellington and Osborne 2001; Winokur and Worth 2006; UC Museum of Paleontology 2014).

Additionally, providing students with a variety of ways to explore scientific concepts, especially those in which students are actively engaged in the “doing” of science, enhances understanding (Dewey 1938). As Dewey stated, “Scientific principles and laws do not lie on the surface of nature. They are hidden, and must be wrested from nature by an active and elaborate technique of inquiry” (Dewey 1920, p. 32). Active science explorations, combined with the use of academic language, will allow students to better explain their thinking.

Lastly, the teachers we worked with are innovative and creative master teachers; they strive to develop new ways to promote student learning and engage their students every day. This study helped them to better realize the importance of active engagement and use of academic language in the science classroom. As these teachers worked to rebuild students’ alternate conceptions in meaningful and lasting ways, they watched their students gain confidence and increase their ability to more accurately explain science concepts. We believe that the process of assessing and analyzing students’ prior knowledge in science, as described in this article, will be necessary for all science teachers, especially as the NGSS are adopted by increasingly more states.

References
American Association for the Advancement of Science (AAAS). 2014. AAAS science assessment: Topics.
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http://assessment.aaas.org/topics.

Resources
AAAS science assessment topics—http://assessment.aaas.org/topics
Classification diagram—www.pac.dfo-mpo.gc.ca/education/images/intermediate/porpoise-marsouin/class.gif
North American mammals—www.mnh.si.edu/mna
Operation Physics—www.amasci.com/miscon/opphys.html
Photosynthesis—www.growingthenextgeneration.com/agrium-games/Animation
A private universe—www.learner.org/resources/series28.html
What's a mammal?—www.discoveryeducation.com/teachers/free-lesson-plans/whats-a-mammal.cfm

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