MINIMIZING MISCONCEPTIONS

Tools for identifying patterns of reasoning
For many years I was frustrated by my students' inability to grasp certain chemistry concepts. Over time I recognized that I was not adequately addressing student misconceptions about scientific ideas. My teaching philosophy was radically changed by the basic understanding that all human beings develop intuitive ideas to explain the behavior of the natural world and that these ideas strongly influence what and how we learn in the science classroom. Finally, I understood why my students had so much difficulty learning scientific concepts.

Pandora's box

With a newfound enthusiasm for constructivist ideas in education, I read numerous research papers and books on student misconceptions in various scientific disciplines, particularly chemistry. I made a list of chemistry misconceptions by topics, such as atomic structure, mole concept and stoichiometry, changes of state, chemical reaction, molecular structure and polarity, acids and bases, and electrochemistry. However, the list grew in an uncontrollable manner. Many students, for example, think the size and mass of an atom change during a phase transformation; perceive "heat" as a fluid; think heat is always needed to start a chemical reaction; do not understand the difference between an element, compound, and mixture; believe that gases do not have any mass; think ionic compounds are composed of molecules; and make no distinction between atomic and molar mass.

How could I expect to identify and modify the innumerable list of misconceptions held by my students? And how could I not try to do so? Gradually, the immensity of the task became overwhelming and my initial enthusiasm was replaced by panic and a sense of futility. No teacher could remember and identify all the misconceptions held by every student and, in addition, design challenging activities to help students build a better understanding. I felt as if I had opened Pandora's box of misconceptions and didn't know how to close it.

I have witnessed many master and novice teachers pass through similar emotional stages when faced with the vast array of misconceptions. Although many teachers recognize the crucial role that students' previous ideas play in their learning and want to help them build a better understanding, they also know that the list of misconceptions seems endless and that students' intuitive ideas are very difficult to change. Some teachers even feel threatened by the topic. The recognition of their own misconceptions makes them feel vulnerable, and they tend to minimize the importance of the problem.

This is a pivotal time in history—research on science education is providing teachers with useful tools to foster student understanding. Research on how people learn is too valuable to be lost or ignored because of fear, frustration, or a sense of helplessness. Therefore, I have learned to minimize my frustration and sense of being overwhelmed by recognizing patterns in students' misconceptions.

Common sense reasoning

My work on misconceptions in science became less overwhelming once I realized many of the ideas are products of only a few patterns of reasoning people commonly use. Researchers say the conceptual difficulties of many students result from reasoning based on "common sense" (Driver, Guesne, and Tiberghien 1985). The common sense approach is characterized by the use of a limited number of patterns of reasoning that people unconsciously follow and apply without either hesitation or need to consider other alternatives (Driver, Guesne, and Tiberghien 1994). As many teachers know, students tend to generate quick explanations of natural phenomena without much reflection, based on intuition and broad generalizations. In other words, students are experts in common sense problem solving.

Sometimes when students face a new problem, they tend to look for information and build generalizations in order to predict and control the phenomenon. Explanations are generally simplified ways of understanding a problem developed through personal experiences. For example, if we have a stomach ache, our first thought points towards something that we ate. A cause is searched for that is close both in time and proximity. These patterns of reasoning help us simplify the complexity of the world and are very useful in daily life because they frequently yield the right solution and do not demand too much effort. Unfortunately, common sense reasoning is also
### Eight patterns of reasoning.

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<td><strong>Students build many of their explanations based on the following assumptions:</strong></td>
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| 1 An active agent is always directly responsible for changes observed in a system. Students analyze phenomena as a sequence of causes and effects. They think that a specific cause always produces the same effect, and that the relationship between them is directly proportional (more implies more). | Heat is always needed to start a chemical reaction.  
If you heat a body, its temperature always rises.  
The more electrons an atom has, the larger it is. |
| 2 Most properties or changes in a system depend on a single independent variable. Students tend to focus their attention on the variable whose change is most evident. | The atomic size only depends on the number of electrons in the system.  
The polarity of a molecule only depends on the polarity of its bonds. |
| 3 Perception is an infallible tool to determine what changes and remains unchanged in a system. Students’ reasoning is guided by what they observe, not by the search for conserved quantities or qualities that are not necessarily perceptible. | Mass is not conserved during a chemical reaction.  
The chemical identity of substances changes during a change of state. |
| 4 Matter is essentially as it is perceived. Students think that the characteristics of the microscopic models of matter are very similar to the observable properties of the macroscopic systems under study. They use reality to explain the model and not vice versa. | Matter is continuous.  
Copper atoms have the properties of bulk copper.  
Molecules expand when heated.  
Water vapor molecules weigh less than ice molecules. |
| 5 The microscopic world is essentially static. Students pay more attention to structural features (such as the distribution of atoms in space), than to dynamic features (such as particle speeds and interactions) when using particulate models of matter to explain chemical phenomena. | Electrons in a chemical bond are fixed in space.  
Atoms in a solid do not move.  
All chemical transformations cease at chemical equilibrium. |
| 6 There is a one-to-one correspondence between the model and reality. Students think that images, analogies, or symbols used in the classroom to represent abstract concepts correspond to concrete reality. | Atoms are like a small solar system.  
Heat has the properties of matter and behaves like a fluid.  
Chemical bonds are concrete physical entities made of matter. |
| 7 Scientific laws or principles can be applied to any system or process, regardless of the particular characteristics of the system or the conditions under which the process occurs. Students do not recognize the conditions in which laws apply. | All compounds are made of molecules.  
The entropy of a system always increases.  
Chemical changes are always irreversible. |
| 8 The formal distinction between related scientific concepts is unimportant. Students build their explanations using concepts that are arbitrarily selected from sets of undifferentiated ideas. They do not see the need to discriminate between them. | Temperature is a measure of a body’s heat.  
Compounds are a type of mixture.  
Intermolecular forces are a type of energy. |
responsible for a great number of the misconceptions held about the behavior of the natural world. For example, children who surmise that condensed water on the outside of a glass is liquid that has filtered through the walls are using common sense; they are looking for the most plausible cause given their perception of proximity in space.

Eight rules

A thorough analysis of students' alternative conceptions in chemistry, as described in the research literature in science education, together with the practical knowledge I have developed working in the secondary school classroom, have helped me identify at least eight patterns of reasoning or "rules" that seem to underlie most of chemistry students' misconceptions (Garnett, Garnett, and Hackling 1995; Nakhleh 1992) (Figure 1). The recognition of these eight rules has provided a framework useful in understanding and even predicting many students' learning difficulties. By distinguishing clear patterns of reasoning, teachers can face the long list of student misconceptions without feeling overwhelmed.

The eight rules have become extremely useful planning and assessment tools that guide many of my decisions and actions in the classroom. Now, when preparing a lesson, I try to identify the ways in which patterns of reasoning could mislead students' interpretations of chemical phenomena. The analysis is helpful in selecting or designing activities that better elicit or challenge students' thoughts and guides teacher thinking when building explanations or posing questions.

Simply useful

The list of reasoning rules is not necessarily complete—the complexity of our thought processes cannot be reduced to a limited number of simple rules that are always applied in the same way, regardless of the context or the individual. However, my experience tells me that this simplification is a very useful teaching tool. For example, at the completion of teaching an introductory chemistry course at my university, one student cornered me with the following argument: cations should always be bigger than neutral atoms or anions because they are "more positive." In actuality, positive ions (cations) tend to be smaller than the corresponding neutral atoms because they have lost electrons. After identifying what patterns of reasoning made him reach such a conclusion, I tried to help him understand how reasoning by common sense led him to the wrong deduction. The student was using a combination of patterns 1 and 2 (Figure 1). He identified the most evident variable that was changing, "the atom has more charge," and he established a simple causal relationship between charge and size (more is more), "more charge implies bigger size." We discussed what it means to have "more positive charge" and "more negative charge," and the relationship with the number of electrons in an atom.

In the last 20 years, many research projects in science education have yielded results that are relevant to the work teachers do everyday in the classroom. Un-

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fortuitously, research and educational practice seem to occur in two isolated worlds, and research results seem too foreign, too complex, or too difficult to apply to the classroom. Science teachers, teachers of science teachers, and researchers in science education have the responsibility to devise ways to bring to the classroom what we know about how students learn. We need to analyze, synthesize, and reformulate research results to create multiple representations that teachers can recognize as a source of useful ideas and practical tools for our work in the classroom.

Vicente Talanquer is an associate professor in the Department of Chemistry at the University of Arizona, Tucson, AZ 85721; e-mail: vicente@u.arizona.edu.

References


