How can changes be controlled?

(the question of Control)

Chemical thinking is applied in diverse contexts to figure out how best to control the properties of a system or the outcomes of a process. We may be interested in, for example, controlling the rate at which milk or other food products decompose (spoil). We may want to reduce the amounts of pollutants that escape from a car's exhaust. Many people are currently working on trying to figure how to reduce the concentration of CO_2 in the atmosphere, increase the storage capacity of electrical batteries, and control chemical processes inside our body to slow aging, avoid diseases, and even augment our bodies' natural abilities.

No matter what types of systems or processes we are seeking to affect, there are common chemical ways of knowing, thinking, and acting to gain the desired control. We know that we can either manipulate external conditions, such as temperature, pressure, and nature and amount or light received, or change the chemical composition of a system to control its chemical properties and behaviors. Helping students understand how chemical control is commonly achieved is critical, as we want students to make sense of and critically evaluate the benefits, costs, and risks of proposed interventions to, for example, reduce the rate of global warming, minimize pollution of water sources, or maximize food production and preservation.

Unpacking

There is a wide variety of questions under the umbrella of *chemical control* that we can pose or that students can suggest. These questions open the door to the exploration and discussion of central chemical ideas, disciplinary practices, and ways of reasoning. We just need to ensure that the questions used to guide work in the classroom create opportunities for students to develop the targeted understandings. To do this, it is necessary to "unpack" the central ideas, science practices, and crosscutting ways of reasoning that the selected question or questions would allow us to integrate. To illustrate this unpacking, we can analyze the two examples shown below:

How can we slow down fruit decomposition?

Central Ideas: Chemical reactions are often responsible for decomposition processes. Reaction rates can be controlled by changing temperature and contact between reactants.
Science Practices: Planning and carrying out investigations; analyzing and interpreting data; constructing explanations and designing solutions
Crosscutting Reasoning: Cause and effect; stability and change

How can we maximize the usable energy output in a combustion?

Central Ideas: Chemical reactions absorb or release energy. The amount of energy exchanged depends on the nature and amounts of reactants.
Science Practices: Planning and carrying out investigations; developing and using models; engaging in argument from evidence
Crosscutting Reasoning: Energy and matter; systems and system models; stability and change

The examples presented in the previous page are not very elaborated, but they illustrate the type of reflection that is needed to identify the major learning targets when students engage in exploring and finding answers to a given question. The selected questions are somewhat specific to facilitate planning and guidance of student work, but still open enough to allow for different groups of students to explore different types of systems depending on their own ideas and interests (e.g., different types of fruits, different types of control strategies). The search for answers to these questions creates opportunities to build connections with other essential questions related to the identity of system components, the relationships between their structure and properties, the various models of chemical change, and the major drivers that cause a given change.

Once the targeted understandings are identified, integrated performance expectations should be built to define what students should be able to do by the end of their exploration. For example:

- *Design a strategy to preserve an assigned food product and justify their ideas based on a) the chemical composition and structure of major components; b) the effects of different environmental variables.*
- *Evaluate different combustion devices based on the analysis of their usable energy output and their effects on their surroundings.*

Eliciting and Exploring

If we want students to develop productive ways of knowing, thinking, and acting in chemistry we need to begin by creating opportunities for them to explore the properties of the systems or processes of interest. They need to start thinking about why and how things change, and how the changes can be controlled. Teachers should take advantage of such exploratory moments to elicit students' initial ideas and ways of reasoning, seeking to identify both productive student ideas that may help advance student thinking and challenges that may hinder the development of targeted understandings. Teachers can be in a better position to build upon students' productive resources and foster student understanding of chemical control when they characterize how students intuitively think about how to control the properties and behaviors of matter, and what types of implicit assumptions students make about what causes a system to change.

Advancing and Connecting

Novice chemistry students often express naïve ideas about how and why things change, and what is needed to induce such change. For example, it is common for students to think that substances change because they want to become more stable or that effort is always needed for things to change. They are often satisfied with these types of rationales and need to be pressed to consider and evaluate alternative explanations. They also often shortcut their reasoning by building simple one-to-one associations of the form more-A-more-B (e.g., the higher the temperature the higher the energy), and need to be guided to test these ideas and connect them to others with causal explanations (e.g., how a change in temperature may increase the rate of a reaction but result if the formation of less product). Working with students to help them evaluate, connect, and integrate basic ideas is critical to supporting the development of chemical thinking, and multiple opportunities need to be opened by teachers to reinforce such connections.