Crosscutting Concepts as Productive Ways of Thinking

VICENTE TALANQUER

The *Framework for K–12 Education* and the *Next Generation Science Standards* (*NGSS*) encourage us to actively engage students in learning experiences that help them integrate core ideas in a discipline, central science and engineering practices, and crosscutting concepts (NRC 2012). However, in my own work with chemistry students, as well as with secondary school teachers and preservice teachers, I long struggled to integrate crosscutting concepts in meaningful ways. I had discussions about energy and matter, structure and properties, systems and system models, and stability and change in my classes. But these discussions seemed disconnected from the major tasks with which we were engaged.

My ability to design lessons, orchestrate learning environments, and build assessments in which I felt core ideas, practices, and crosscutting concepts were seamlessly integrated significantly improved when I started thinking about crosscutting concepts in a different way. Rather than thinking of them as additional content that I had to somehow include in my lessons, I began to conceptualize them as "ways of thinking" that I wanted my students to develop. I was still interested in my students understanding what a model was or recognizing the relationship between the structure of a system and its properties or functions. But my central goal became for them to develop the productive ways of thinking that the different crosscutting concepts encapsulate. Let me elaborate on this idea.

Integration of the crosscutting concept "Structure and Function," for example, seeks to highlight that the structure of any type of system—physical, chemical, or biological—determines many of its properties and functions. This concept, however, is more than an organizational schema for interrelating knowledge from different science fields. It points to ways of reasoning that are quite productive in analyzing data, generating models, making predictions, and building arguments and explanations in those fields. In chemistry, for example, many relevant questions are answered by analyzing the submicroscopic structure of the systems of interest and applying structure-property relationships to infer their properties and behaviors (Talanquer 2018). It is through this way of thinking that one can integrate fundamental chemical knowledge about substances and processes with major disciplinary practices, like analyzing materials in the surroundings, synthesizing new substances, and controlling targeted processes (Sevian and Talanquer 2014).

Consider now the crosscutting concept "Cause and Effect." We certainly want our students to recognize that all events in their surroundings have causes, sometimes simple and sometimes complex. In my perspective, what the integration of this crosscutting concept should enable is students' ability to engage in mechanistic reasoning (Russ et al. 2008). In other words, foster their ability to make sense of a phenomenon by identifying core components in a system of interest, analyzing their interactions, and recognizing how the organization of these components brings about the event. The opportunities that we create for students to develop and apply mechanistic reasoning can also enhance their understanding of other crosscutting concepts, such as "Systems and System Models" and "Scale."

All crosscutting concepts, including "Energy and Matter" or "Stability and Change," point to ways of reasoning used productively across disciplines to make sense of phenomena, predict behaviors, and control outcomes. For example, being able to track matter and energy flow during a chemical reaction is critical for making predictions about the directionality and rate of the process. Similarly, being able to predict how different factors affect the stability of a system is of central importance to regulate its behavior.

In Practice

Thinking of crosscutting concepts as productive ways of reasoning to be developed by students rather than as content to be learned has helped me identify strategies to better foster the integration of the three major dimensions in the *Framework* and the *NGSS*. In particular, it has guided me in the creation of different types of scaffolds that I use to support my students as they engage in the analysis of data, the development and application of models, and in the construction of arguments and explanations. One of these scaffolds is presented in Figure 1 as an example, although I often make modifications based on the nature of the phenomenon under investigation and the learning goals.

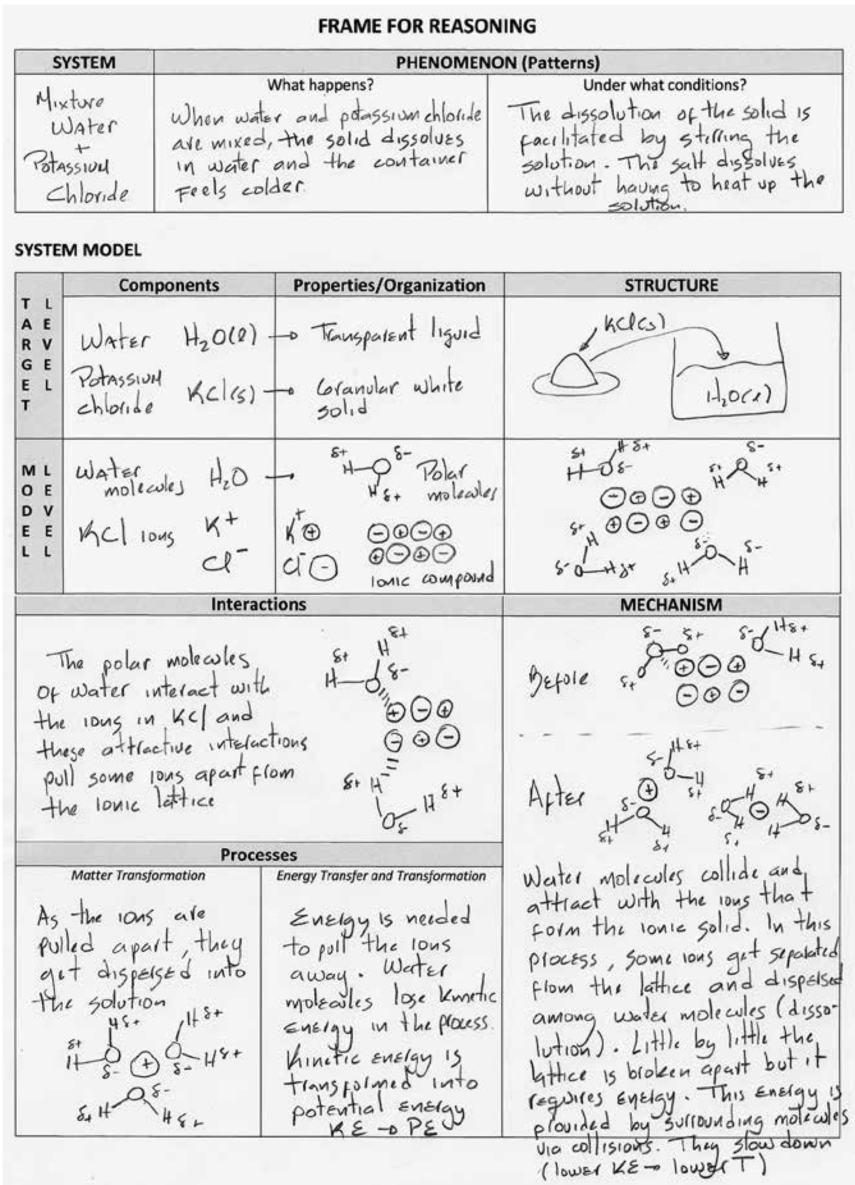
The scaffold in Figure 1 guides students in the description of the characteristics of the system and processes under analysis, and in the construction of a system model that can be used to make sense of the targeted phenomenon (endothermic dissolution of an ionic salt). Students are asked to identify major components and characterize their properties and structure at different scales. They are prompted to analyze relevant interactions between components, and to discuss how those interactions enable processes that result in matter transformation and energy transformation and transfer. Finally, ideas have to be integrated in the elaboration of a mechanism that explains the phenomenon and can be used to support predictions. The example presented in Figure 1 was built in a chemistry class, but the structure of the scaffold is discipline-independent and can be used to make sense of different types of problems and phenomena in a variety of content areas.

Scaffolding tools such as the one illustrated in Figure 1 can serve multiple purposes. They guide students in the integration of ideas, practices, and ways of thinking. They make explicit the different ways of reasoning in which we want them to engage, and they help make student thinking visible. From this perspective, they can be used in diverse and flexible ways in the classroom. A teacher may use them as guiding tools to help structure student reasoning or as formative assessments that create opportunities to provide feedback as students develop understanding. They can also be used as summative assessment instruments in which students are asked to individually or collaboratively apply what they have learned to make sense of a phenomenon. The structure of the scaffold facilitates grading of student work as specific rubrics can be developed for each of its major components.

The different sections in a "frame for reasoning" can be completed in a single class session or at different times throughout a learning sequence depending on a lesson's goals. Sometimes I introduce a phenomenon to my students and ask them to just describe what happens and under what conditions. Then, we engage in activities that allow me to introduce core concepts and ideas before I asked them to engage in modeling the targeted phenomenon and building a mechanistic explanation. I often ask students to complete their own frame of reasoning but allow them to share

FIGURE 1

Example of scaffolding tool used to guide the analysis of phenomena using crosscutting ways of reasoning.


FRAME FOR REASONING

SYSTEM	PHENOMENON (Patterns) What happens?	PHENOMENON (Patterns) Under what conditions?
Mixture Water + Potassium Chloride	When water and potassium chloride are mixed, the solid dissolves in water and the container feels colder	The dissolution of the solid is facilitated by stirring the solution. The salt dissolves without having to heat up the solution.

SYSTEM MODEL

	Components	Properties/Organization	STRUCTURE
TARGET LEVEL	Water $H_2O(l)$ → Transparent liquid; Potassium chloride $KCl(s)$ → Granular white solid		KCl(s), $H_2O(l)$
MODEL LEVEL	Water molecules H_2O → Polar molecules; KCl ions K^+ Cl^-	Ionic compound	

Interactions: The polar molecules of water interact with the ions in KCl and these attractive interactions pull some ions apart from the ionic lattice

MECHANISM: Before / After

Processes — Matter Transformation: As the ions are pulled apart, they get dispersed into the solution

Processes — Energy Transfer and Transformation: Energy is needed to pull the ions away. Water molecules lose kinetic energy in the process. Kinetic energy is transformed into potential energy KE → PE

Water molecules collide and attract with the ions that form the ionic solid. In this process, some ions get separated from the lattice and dispersed among water molecules (dissolution). Little by little the lattice is broken apart but it requires energy. This energy is provided by surrounding molecules via collisions. They slow down (lower KE → lower T) ideas in small groups. Students can also be asked to share their frames with their peers to receive formative feedback on the different sections on which they are working. Teachers can also organize whole-class discussions in which a collective frame of reasoning is built by the class with input from all students.

Final comments

The *Framework* and *NGSS* invite us to design creative learning experiences that help students integrate knowledge, practices, and ways of reasoning that are productive in making sense of and acting on the world (NRC 2012). It is common, however, for teachers to emphasize central ideas and scientific practices in the lessons that we design. A careful analysis of the crosscutting concepts included in the *Framework* shows that they are more than organizational schemas that interrelate knowledge from different scientific fields. They also encapsulate overarching ways of thinking that we should help our students to develop. In my practice, focusing on these ways of reasoning has enabled me to more easily plan and implement learning experiences that integrate the knowing, the thinking, and the acting that we value.

REFERENCES

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

Russ, R.S., R.E. Scherr, D. Hammer, and J. Mikeska. 2008. Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education* 92 (3): 499–525.

Sevian H., and V. Talanquer. 2014. Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research and Practice* 15 (1): 10–23.

Talanquer, V. 2018. Progressions in reasoning about structure–property relationships. *Chemistry Education Research and Practice* 19: 998–1009.

Vicente Talanquer (*vicente@u.arizona.edu*) is a Distinguished Professor in the Department of Chemistry and Biochemistry at the University of Arizona in Tucson.