Chemical Solitaire

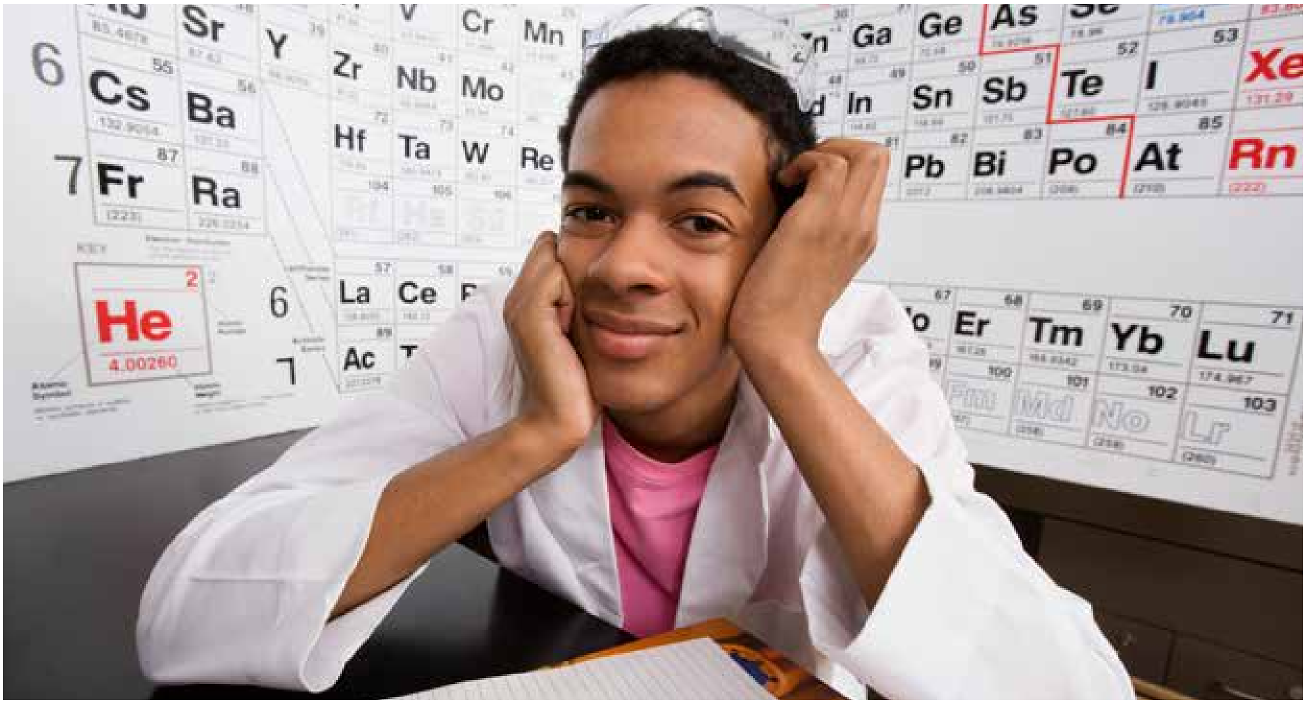
Arranging cards to build an organizational model of the elements

Joanna Philippoff, Kanesa Duncan Seraphin, Jennifer Seki, and Lauren Kaupp

The periodic table does more than provide information about the elements. The periodic table also helps us make predictions about how the elements behave. Understanding the atomic structure of matter and periodic properties of the elements, as shown in the periodic table, is fundamental to many scientific disciplines. Unfortunately, high school students often view the periodic table as an overwhelming jumble of numbers and letters to be memorized, rather than a model with predictive and explanatory power.

This article presents an activity that uses the rich history of the development of the periodic table to promote understanding of how the elements are organized. By arranging three sets of cards, students connect to the individuals in history whose creativity and imagination laid the groundwork for our evolving comprehension of the patterns in nature. This activity, which has strong connections to the *Next Generation Science Standards* (NGSS Lead States 2013) (see box, p. 49), can be accomplished in as few as two class periods with little prep time or cost.

Improving students' understanding of the nature of science has been an ongoing goal for more than 50 years (Lederman 2007). This activity focuses on three of the nature of science understandings defined by the *NGSS:* scientific knowledge is open to revision in the light of new evidence, scientific knowledge is based on empirical evidence, and science is a human endeavor (NGSS Lead States 2013). Over the 124 years modeled in this activity, advancements in technology allowed for the discovery of new elements and elemental properties, and scientists modified existing elemental organization paradigms to accommodate the new evidence. Similarly, students in this activity revise scientific explanations based on new evidence as they develop classification strategies for the elements. At the end, students



reflect on their reasoning and compare their organization schemes to those of their peers and historical scientists.

Element cards

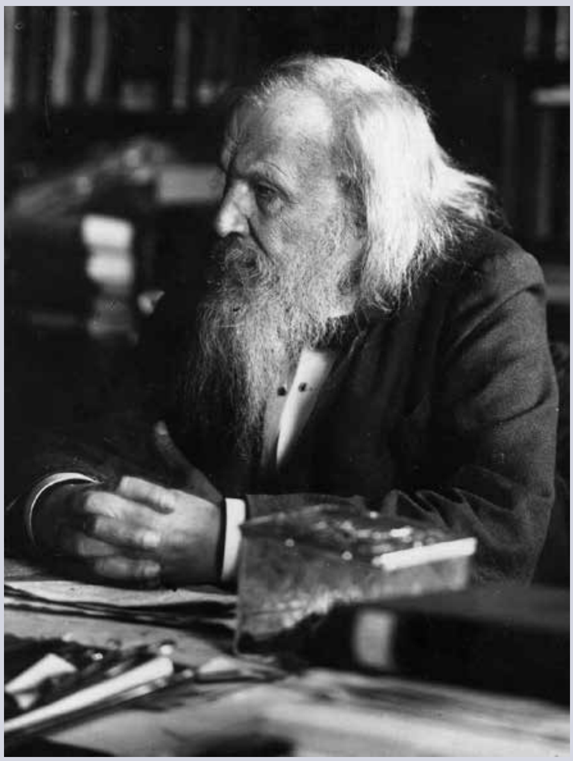
Historical lore says that Russian chemist Dmitri Mendeleev (1834–1907) (Figure 1) wrote the weights and properties of the elements on cards and played "chemical solitaire," organizing them. Although no such cards have been found, the analogy to the popular card game is a useful teaching tool and encourages students to think of multiple ways of classifying the elements. In solitaire, cards are organized by suit and value. Mendeleev developed a periodic table organized by both weight and properties.

In this activity, element cards (provided online; see "On the web") are divided into three sets that correspond to significant advancements in our understanding of how the elements are organized (Figure 2). The colors named below for the card sets correspond to the colors in Figure 2.

- Set A (1789; green): The elements in the list of simple substances that French chemist Antoine-Laurent Lavoisier (1743–1794) developed that correspond to our modern understanding of elements (N=27). The indicated year, 1789, is when Lavoisier published his table; 27 is the number of elements he listed that correspond to our modern understanding of the term.
- Set B (1869; gold): The additional elements known at the time that Mendeleev constructed his first periodic table (N=30).

FIGURE 1

Dmitri Mendeleev, the "father of the periodic table."



SERGE LACHINOV

FIGURE 2

Historical progression of element organization cards laid on the modern periodic table.

Set A (1789) = green, Set B (1869) = gold, Set C (1913) = Blue. (Although highlighted, the lanthanide and actinide series are not included in the activity.)

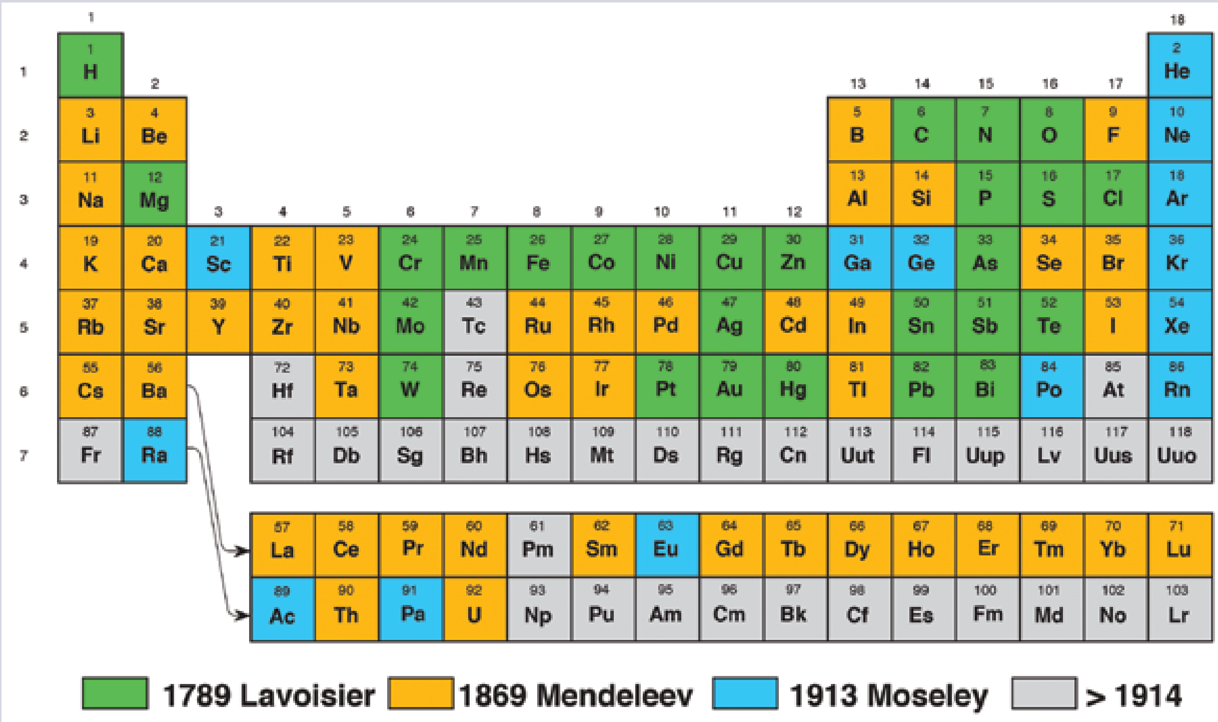


ILLUSTRATION BY BYRON INOUYE. ADAPTED WITH PERMISSION FROM *EXPLORING OUR FLUID EARTH* (SERAPHIN ET AL. 2015).

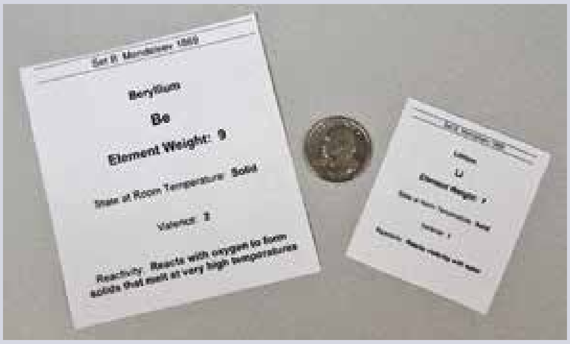
- Set C (1913; blue): The additional elements known when English physicist Harry Moseley (1887–1915) rearranged the periodic table based on atomic number (N=11).

This progression of card sets scaffolds the number of elements students have to manipulate at a time, follows historical discovery, and allows students to arrange more familiar elements first. The year 1913 was chosen for the final card set because it allows students to add the noble gases to their element arrangement and "fill in" some of the potential gaps in their models. However, some elements (colored gray in Figure 2) were still "missing" at this time, including, for example, Technetium, atomic number 43, discovered in 1937.

Each element card has the element name, chemical symbol, element weight, state at room temperature, valence, and reactivity for elements in groups with similar chemical properties (groups 1, 2, 17, and 18). For example, the alkali metal cards read "reacts vigorously with water," and the halogen cards read "reacts with metals to form salts" (Figure 3, p. 46). The cards balance historical accuracy with supporting student understanding. Some listed properties were unknown in 1789; we left out other properties discovered over time. We use *valence*, the most common number of chemical bonds an atom can form and a term known to Mendeleev in 1869, instead of *valence electrons*, the number of electrons in the outermost electron shell of an atom, a concept proposed by chemist Gilbert Lewis in the early 20th century. Scientists understood *valence* before they understood reactivity, which requires understanding the underlying structure of atoms, including the concept of valence electrons. Similarly, we use *atomic weight* instead of *atomic mass* in accord with the terminology used by Mendeleev. This activity is not intended to generate the modern periodic table but to use a historical approach with information modified for simplicity.

FIGURE 3

Element card samples in two sizes.



JOANNA PHILIPPOFF

Connections to nature of science.

Scientific Knowledge Is Open to Revision in Light of New Evidence
Over time, scientists have modified and reinterpreted the periodic table as new information is discovered; students model this progression.

Scientific Knowledge Is Based on Empirical Evidence
Students look for patterns and develop explanations as they develop a series of organizational models reflecting a historical progression of empirical evidence.

Science Is a Human Endeavor
Students apply creativity to solving a problem and recognize how the work of multiple scientists contributed to our modern understanding of the periodic table.

Connections to Engineering, Technology, and Applications of Science
Element classification systems changed over time as improvements in technology allowed for a deeper understanding of atomic structure.

The chemical solitaire activity

This activity can be used in any class that covers introductory chemical concepts. We implemented it in two ninth-grade marine science classes as well as a mixed-grade science elective course in a public charter laboratory school with a student body that reflects the state's diversity. In the ninth-grade classes, the activity took two 45-minute periods during the first week of a chemistry unit. On the first day, students developed their own organization scheme for sequential groups of elements. On the second day students discussed the activity.

Before the activity, the element cards are printed, cut, and placed in three envelopes labeled Set A, Set B, and Set C, respectively. The lanthanide and actinide series are excluded to limit the number of elements students have to organize. You can modify the cards depending on your goals. For example, you could include additional chemical or physical properties, such as boiling and melting points, or, to simplify the activity, you could remove the transition metals. Also, consider the area your students will have to work with; for smaller areas, we recommend reducing the size of the cards.

To introduce the activity, we ask students to define or give examples of elements, which exposes their prior knowledge and conceptions. For example, some students might list fire, water, wind, and earth as "elements," which is how Plato and other classical Greek philosophers originally classified matter. Rather than share the modern definition, we told students they would explore this concept throughout the unit, and they didn't have to understand all of the properties listed on the element cards at first.

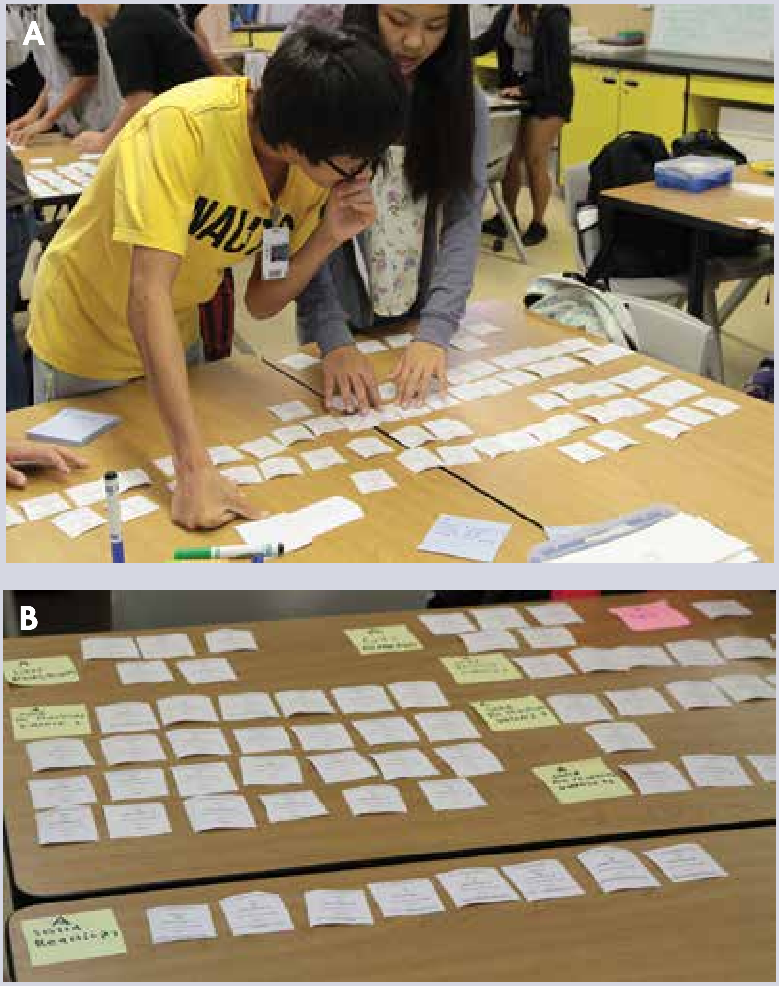
We framed the activity—sorting sets of element cards using students' own system of organization—as an exploration of science, history, and modeling. This activity models the approach and struggles of historical scientists: Students will sequentially "discover" new elements. As they receive new information, they will have to incorporate it into their existing organizational framework. Students are expected to share not only their final model but also the reasoning behind their scheme.

Students are arranged into groups of three to five and given approximately 10 minutes with card Set A. We ask students to "develop a system of organization for elements based on their physical properties." Because this Set A includes elements from across the periodic table, it is difficult for some students to find trends. This mimics the historical progression; more elements needed to be discovered before clear patterns emerged. Next, we give students 10 minutes with card Set B and then 5 minutes with Set C (Figure 4). As students receive new information, we encourage them to modify their model, reflect on the reasons for their organization, and record their thought processes. This enhances student learning and comprehension of complex concepts such as the nature of science (Hattie 2009; Seraphin et al. 2012). Questions we ask during the activity include:

- What information are you using to decide how to arrange the elements?
- Why did you group these elements together?
- Why do you think this/these cards do not seem to "fit"?
- How can you make connections between elements or groups of elements?

FIGURE 4

Students organizing element cards (A). In this group's model, students organized the elements into non-connected clusters based on state and reactivity (B).



JOANNA PHILIPPOFF

It's critical for students to build and revise at least three different models of periodic arrangements. Students come up with a model based on limited data and modify their ideas as new information comes to light. This process emulates how, as technology improves and new evidence is uncovered, models, such as classification systems, change over time. By evaluating and refining their models, students develop an understanding of how models have predictive and explanatory power. By comparing their final organization to the modern periodic table, your students can determine if they predicted the discovery of these elements.

After receiving card Set C, students finalize their organizational model. Then they do a gallery walk to share their products and reasoning. Pictures of student work are useful to reference when discussing the activity and for assessment purposes. At this point, we share images of the historical progression of the periodic table (e.g., Figure 5, p. 48) and alternative models that emphasize properties of the elements that are not as apparent in traditional periodic tables (e.g., Figure 6, p. 48). Sharing these models supports creative student organizational strategies that are different from the modern periodic table. There are many "right" answers! As students organized their results, guiding questions include:

- How did your group organize the elements? Explain your process of organization.
- Did your group change your organization strategy at any time during the activity? If so, explain what you started doing and what you changed.
- After everyone shared in class, did you want to change how you organized the elements? If yes, explain how. If not, explain why you think your group's strategy was "best."
- Compare your organization to the modern periodic table; comment on how they are similar and different.
- How did this activity mimic what scientists have done in the past, and what they do today?

FIGURE 5

Lavoisier's "Table of Simple Substances."

192 DES SUBSTANCES SIMPLES.

TABLEAU DES SUBSTANCES SIMPLES.

	Noms nouveaux.	Noms anciens correſpondans.
Subſtances ſimples qui appartiennent aux trois règnes & qu'on peut regarder comme les élémens des corps.	Lumière	Lumière.
	Calorique	Chaleur. Principe de la chaleur. Fluide igné. Feu. Matière du feu & de la chaleur.
	Oxygène	Air déphlogiſtiqué. Air empiréal. Air vital. Baſe de l'air vital.
	Azote	Gaz phlogiſtiqué. Mofete. Baſe de la mofete.
	Hydrogène	Gaz inflammable. Baſe du gaz inflammable.
Subſtances ſimples non métalliques oxidables & acidifiables.	Soufre	Soufre.
	Phoſphore	Phoſphore.
	Carbone	Charbon pur.
	Radical muriatique	Inconnu.
	Radical fluorique	Inconnu.
	Radical boracique	Inconnu.
Subſtances ſimples métalliques oxidables & acidifiables.	Antimoine	Antimoine.
	Argent	Argent.
	Arſenic	Arſenic.
	Biſmuth	Biſmuth.
	Cobolt	Cobolt.
	Cuivre	Cuivre.
	Etain	Etain.
	Fer	Fer.
	Manganèſe	Manganèſe.
	Mercure	Mercure.
	Molybdène	Molybdène.
	Nickel	Nickel.
	Or	Or.
	Platine	Platine.
	Plomb	Plomb.
	Tungſtène	Tungſtène.
	Zinc	Zinc.
Subſtances ſimples ſalifiables terreuſes.	Chaux	Terre calcaire, chaux.
	Magnéſie	Magnéſie, baſe du ſel d'Epſom.
	Baryte	Barote, terre peſante.
	Alumine	Argile, terre de l'alun, baſe de l'alun.
	Silice	Terre ſiliceuſe, terre vitrifiable.

AMITCHELL125

FIGURE 6

An example of an alternative periodic table.

Paul Giguère's 3-D, flower-like periodic table consisting of four connected loops (1966).

ALMAAK

Students also complete these questions individually for homework as a written formal assignment. Students are assessed based on the richness of their explanations of their groups' reasoning and thought processes. The teacher uses these assessments to help tailor subsequent lessons.

This activity serves as the foundation for understanding patterns in the periodic table, including the importance of valence electrons in chemical reactivity and bond formation. After further learning, students can apply their knowledge of the periodic table by completing this activity again as a summative assessment.

Outcomes

In our classes, students primarily organized the elements based on weight or state of matter and secondarily grouped them by valence or reactivity. In the mixed-grade class, upper-level students (taking physics or chemistry) prioritized valence and reactivity. For example, one group focused first on valence, separating Set A cards into groups. With the addition of card Set B, they further split the elements into piles based on reactivity; elements with no listed reactivity were sorted by valence. Lastly, with card Set C, they rearranged the elements into groups based on atomic mass.

All students reported that the activity increased their understanding of how elements are organized, their interest in the periodic table, and their understanding of the nature of science (Figure 7, p. 50). Students said they enjoyed working with group members, "actually physically sorting out the elements," being creative in their organization methods, and seeing how different groups organized the elements.

In written reflections, some students described how they did not want to change their first level of categorization, even after being exposed to other groups' models. Rather than reexamining their organization strategies to create new models, the new sets of cards and their peer observations encouraged them to further divide rather than link the elements.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectation listed below.

Standards
HS-PS1 Matter and Its Interactions
Performance Expectation
HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

Dimension	Name and NGSS code/citation	Specific Connections to Classroom Activity
Science and Engineering Practices	Developing and Using Models • Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1) Obtaining, Evaluating, and Communicating Information • Communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats	Students develop and revise models of how the elements are organized based on evidence and compare their models to accepted scientific models. Students gather information from the element cards, communicate their organization scheme and reasoning, and evaluate different organization strategies.
Disciplinary Core Idea	PS1.A Structure and Properties of Matter • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	Students classify elements based on their chemical and physical properties.
Crosscutting Concept	Patterns • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1)	Students identify patterns in element properties and use these patterns as evidence to support their organizational scheme.

Common Core State Standards (NGAC and CCSSO 2010)

- ELA-LITERACY.RST.9-10.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.
- ELA-LITERACY.RST.11-12.5. Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.
- CCSS.MATH.PRACTICE.MP3. Construct viable arguments and critique the reasoning of others.
- CCSS.MATH.PRACTICE.MP7. Look for and make use of structure.

C3 Framework For Social Studies State Standards

- D2.His.9.9-12. Analyze the relationship between historical sources and the secondary interpretations made from them.

FIGURE 7

Results of ninth-grade student feedback survey (N = 47).

Each question was on a scale of 1–5, with 1 = "the activity did not increase my understanding/interest" to 5 = "the activity greatly increased my understanding/interest."

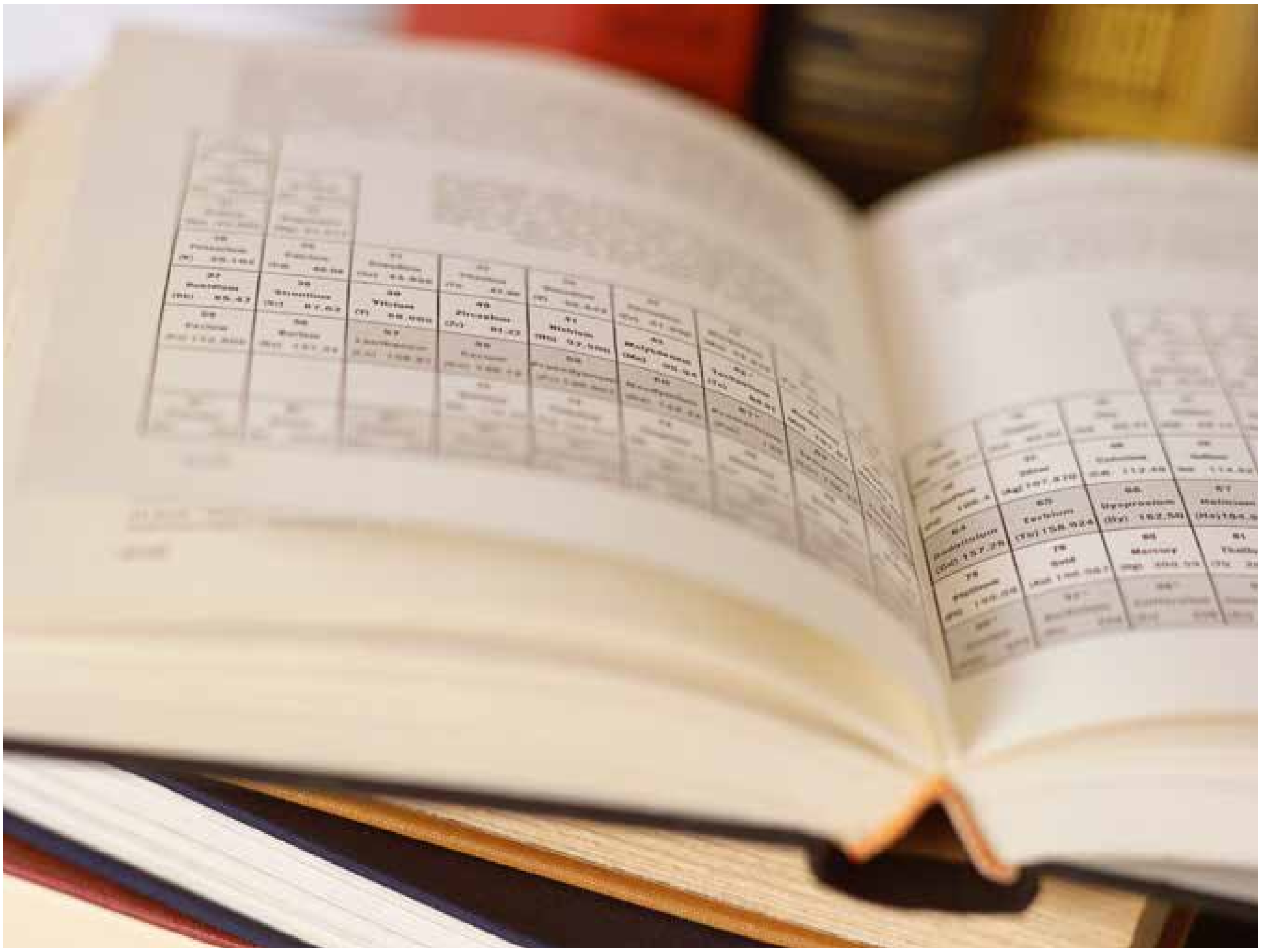
Construct	Prompt	Mean	Standard Deviation	Sample Student Comments
Content Understanding Periodic Table Trends	To what extent do you think doing this activity increased your understanding of how elements are organized?	3.34	0.87	"I liked organizing the elements, and finding new ways to organize them was really helpful to understanding the periodic table better." "I liked how we needed to find different ways to organize the elements and also find out what the elements have in common with each other."
History of Science	To what extent do you think learning about the history of the periodic table increased your interest in the periodic table?	3.17	0.92	"I thought this activity was really good because we got to see how many more elements were added throughout time."
Nature of Science Scientific Knowledge Is Open to Revision in Light of New Evidence	To what extent do you think organizing the elements increased your understanding of how scientific knowledge builds and changes over time?	3.51	0.80	"I liked how we only knew limited information first, then we realized how different what we thought before was after." "I liked how we were able to work together and that we were able to see the development of scientific findings."
Nature of Science Science Is a Human Endeavor	To what extent do you think organizing the elements increased your own understanding of the importance of imagination and creativity in science?	3.49	0.93	"The best thing about this activity was getting to organize the elements in ways we created ourselves because that is how we understood them."

Students were more attached to their original models than we anticipated, perhaps because they didn't want to think of their original models as "incorrect." This reflects the challenges in teaching the nature of science through inquiry. Besides discussing these issues with students during and after the activity and increasing the time students spend with Set A, having students share their reasoning through their first model may help emphasize the process rather than the product.

The teacher in our example—one of the authors—was implementing this activity for the first time. She noted: "The lesson was very engaging for the students, even with very little prior introduction to the topic. Most students were actively engaged in the post-activity discussion. Students seemed to like the idea that they had done an activity that mimicked what scientists did in the past in order to study and organize the elements."

Conclusion

Emulating the scientific process using historical examples can develop students' understanding of the nature of science. They gain an appreciation



that scientific knowledge is based on empirical evidence, is open to revision in the light of new evidence, and is a human endeavor. Experiencing the periodic table through a historical lens enhances student interest, understanding, and engagement in difficult content and helps them connect to the rich history of scientific human ingenuity. ■

Joanna Philippoff (philippo@hawaii.edu) *is a program manager and Kanesa Duncan Seraphin* (kanesa@hawaii.edu) *is an associate professor at the University of Hawaii at Manoa; Jennifer Seki* (jennifer_seki@universitylaboratoryschool.org) *is a teacher at the University Laboratory School in Honolulu; and Lauren Kaupp* (lauren_kaupp/cib/hidoe@notes.k12.hi.us) *is an educational specialist for science and STEM at the State of Hawaii Department of Education in Honolulu.*

On the web

Downloadable elements cards; timeline of events in the construction of the modern periodic table: *www.nsta.org/highschool/connections.aspx*

References

Hattie, J. 2009. *Visible learning: A synthesis of over 800 meta-analyses relating to achievement* (pp. 1–378). New York, NY: Routledge.

Lederman, N.G. 2007. Nature of science: Past, present, and future. In *Handbook of research on science education,* ed. S.K. Abell and N.G. Lederman, 831–879. Mahwah, NJ: Lawrence Erlbaum.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.

Seraphin, K.D., J. Philippoff, L. Kaupp, M.H. Lurie, D. Lin, E. Baumgartner, and F.M. Pottenger. 2015. Exploring our fluid Earth. University of Hawaii. *www.exploringourfluidearth.org.*

Seraphin, K.D., J. Philippoff, L. Kaupp, and L.M. Vallin. 2012. Metacognition as means to increase the effectiveness of inquiry-based science education. *Science Education International* 23 (4): 366–382.