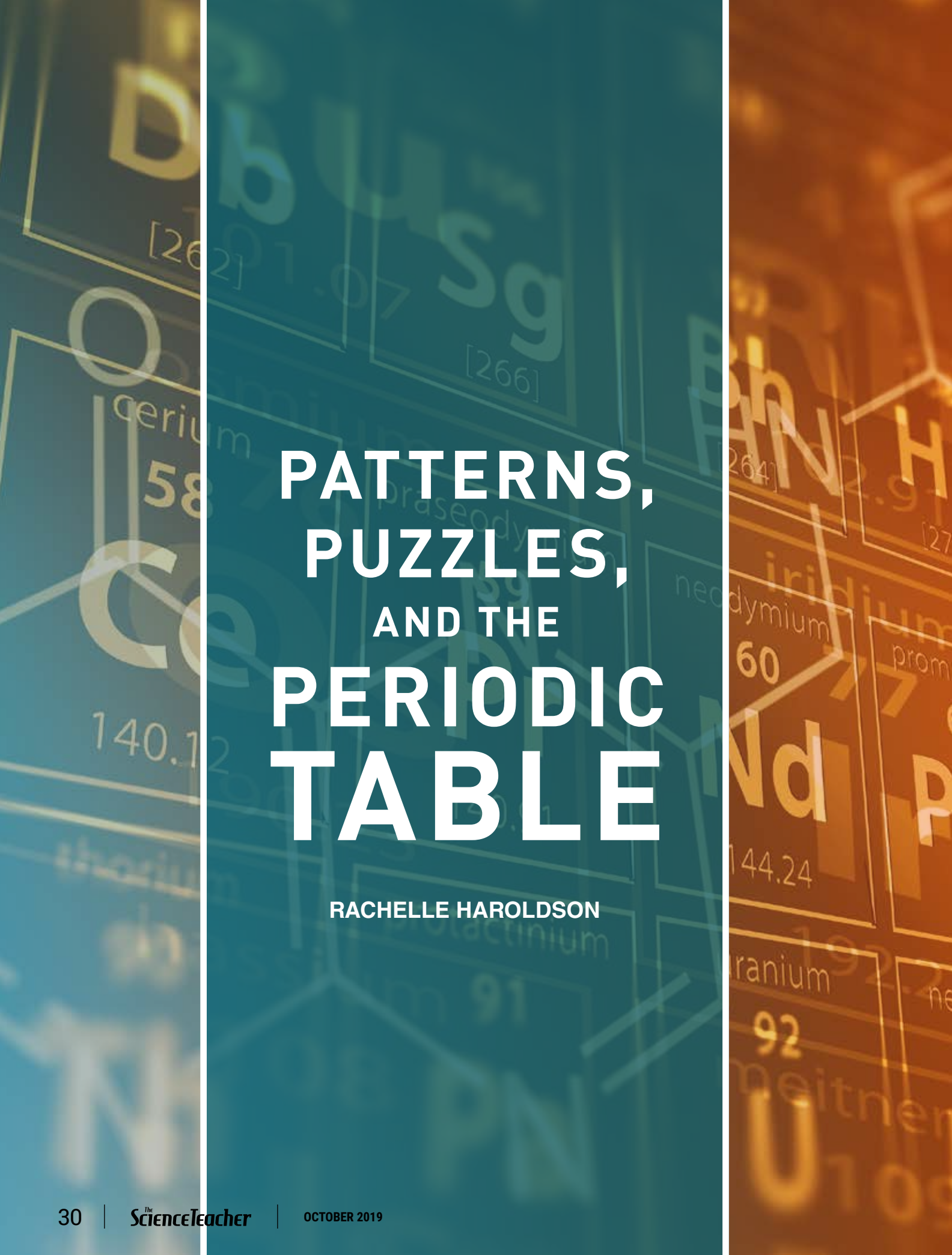


PATTERNS, PUZZLES, AND THE PERIODIC TABLE

RACHELLE HAROLDSON

Teaching the periodic table is a central part of chemistry. This might involve memorizing the symbols of the elements, learning about the properties of the families, or understanding its general organization. This year, The International Year of the Periodic Table, marks its 150th anniversary (see "On the web"), and represents a good opportunity to highlight its history.

The underlying patterns described by periodic law, such that the table is organized horizontally by the number of protons and vertically by similar chemical properties in addition to the repeating patterns associated with those electrons found in the outermost shell of an atom correlate with the *Next Generation Science Standards* (*NGSS*) Disciplinary Core Idea (DCI) Structure and Properties of Matter (PS1.A) (NGSS Lead States 2013). Furthermore, observing patterns and the relationships underlying them is one of the key crosscutting concepts found in the *NGSS* (see NGSS connection box, page 35).

The following lesson requires about two traditional class periods or one block period and follows the 5E Instructional Model designed by the Biological Sciences Curriculum Study (Bybee 2014) with the added Elicit stage proposed by Eisenkraft (2003). Students first emulate Dmitri Mendeleev's own experience with organizing the elements through a puzzle activity, using patterns to make predictions. Then after reading a non-fiction text about his contributions (Bryson 2008), students gain a foundational understanding of the patterns within the periodic table before spending time exploring the properties of the families.

Elicit

Start class by asking students about their experiences with puzzles, if they like puzzles, and what kinds of puzzles they like. Students spend time sharing about their experiences with puzzles and connecting them to their own interests. Explain that today they will be working on some different kinds of puzzles.

Students should have experience with the ideas of Carol Dweck and understand the difference between having a growth mindset and fixed mindset, and what it means to have a mastery response or a helpless response (Dweck 2006; Mindset Works 2016). This is important because many students find science challenging, and having these conversations in the beginning starts to create a culture that welcomes mistakes as part of the learning process. Students are informed that the puzzle will be challenging, and they need to draw on their growth mindset. Reinforce that they absolutely can complete the puzzle and figure out the pattern. In order to do so they will have to persevere.

Before starting the puzzle, the teacher asks the essential question "Where have you seen patterns in your life?" In groups of three to four students they will respond to this question using the Chalk Talk strategy (Ritchart, Church, and Morrison 2011). Students gather around a whiteboard or large poster paper with the essential question written in the middle. Each student has a different colored marker. Set the timer for two minutes and during that time students silently write, draw,

FIGURE 1

Understanding the periodic table puzzle and possible configurations.

respond, pose new questions, and react to each other's responses. Then after the silent dialogue, groups are allowed to talk and discuss what everyone wrote or drew. Students can also do a gallery walk around the room to look at other groups' ideas. In a final discussion the teacher verbally synthesizes their thoughts and looks for themes across the different groups.

Engage and Explore

Students can stay in their Chalk Talk groups or they can be shuffled into new groups. When thinking about the groups, put students together who are going to encourage each other when they struggle.

The puzzle, Understanding the Periodic Table, is a 24-piece set by American Educational, which can be found through science supply stores and online retail distributors at $74.99 (see "On the web"; Figure 1, p. 31). Science teachers could also create their own puzzle if science supply funds are an issue.

Brief the students on the puzzle. The pieces all have a color, whole number, and decimal number with varying numbers of stars, holes, and/or notches on the side. Students have two goals:

- Determine a way to arrange the pieces of the puzzle demonstrating a pattern for each characteristic (color, number, decimal, stars, holes, notches). Before passing out the puzzles, make sure to remove one or two pieces.
- Predict the characteristics of the missing pieces based on evidence from the pattern they developed.

With the right amount of time, every group can figure out the pattern. Some groups will need more time, some groups will need less time. Let students know ahead of time that there are clues should they get really stuck. After 10 minutes, if they do not have at least a pattern for two of the characteristics, students should ask for a hint.

The first hint is related to color. Students are asked about the most common color pattern and most respond with the rainbow pattern or ROY G BIV. Encourage them to arrange the pieces into the rainbow order. Once in the rainbow configuration, students start to see a pattern for the shapes (holes, stars, notches)

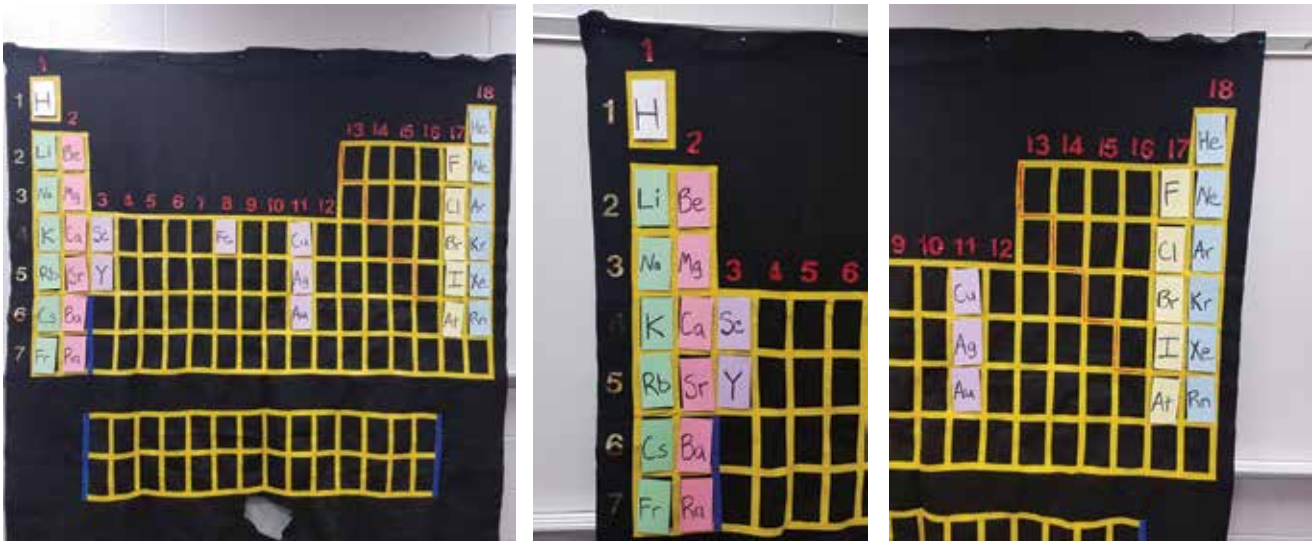
FIGURE 2

Puzzle and Mendeleev discussion questions.

- What patterns did you observe in the puzzle?
- How did you feel while working on the puzzle? What did you do when you started to struggle?
- How was the puzzle activity similar to Mendeleev's experience with the elements?
- Why is it important to understand patterns in science? Why is it important to make predictions in science?
- Are you as confident about your puzzle configuration as Mendeleev was about his element configuration? Why or why not?

FIGURE 3

Wall-size periodic table with elements from some of the families.



and whole numbers. When students notice a discrepancy in the pattern for the shapes, guide them to think about their missing piece. A 6" × 4" arrangement (see Figure 1) allows students to most easily see the pattern (this can be another hint), but other dimensions will work.

Finding a pattern for the decimal numbers happens at the very end for most groups. Having four-function calculators on hand is helpful, as some groups want to do quick calculations to look for a mathematical pattern.

Once students have a pattern for the puzzle, they start to work out the missing pieces. When groups are ready, they describe the characteristics of the missing pieces, justifying what the pieces should look like based on the pattern they have discovered. If they are correct in their prediction, give them the missing pieces and remind them to keep the details of the pattern a secret from other groups still working.

Encourage successful groups to help other groups without giving the answer away. If they are incorrect and there is still time, let them continue to work. If time is running out and they have all of the characteristics except the decimal number, then give them the piece to discuss with their group about where they made the error.

Explain

Bring the students back into one large group, explaining that Dmitri Mendeleev (also spelled Mendeleyev), a Russian chemist, had a parallel experience. With only 63 elements having been discovered in 1869, he was also trying to solve an incomplete puzzle. Inspired by the game Solitaire, he put the names, weights, and properties of the elements on cards, moving them around and re-arranging them until a pattern made sense.

What made Mendeleev particularly remarkable was his confidence in the pattern he observed for the arrangement of the elements, which led him to leave gaps in the periodic table for elements not yet discovered, and to make stalwart predictions of the properties of those undiscovered elements. This is similar to having the students moving their puzzle pieces around, looking for a pattern, justifying the pattern based on evidence, and predicting the characteristics of the missing pieces.

Because of the varying reading levels of students across chemistry classes, I have included several resources for articles about Mendeleev and the periodic table (see "Resources") outlining Mendeleev's struggle, his process for organizing the elements, and his discovery of periodic law. Teachers can choose one article or a few articles and differentiate based on students' reading levels. Students can read the article individually or out loud to each other in small groups.

After reading the articles, students work in their puzzle groups, answering a series of questions (see Figure 2) connecting their experience with the puzzle to that of Mendeleev's with the elements. The goal is for students to recognize the natural emergence of patterns in science as well as the struggle scientists go through when developing explanations. Pre-select a speaker from each group to encourage a broad range of responses during the large group discussion. Encourage students to share about their own struggles, persistence, and pattern development.

Elaborate and Evaluate

After students have learned more about Mendeleev and his contributions, they move on to learn more about the modern periodic table and the specific element families. Show a picture of a family or ask students to share pictures of their own families. Pose the question, "What do families have in common?"

In small groups, have students discuss their ideas, then ask someone who has not shared with the large group yet to share. Students usually mention how families share similar body features, behaviors, mannerisms, hobbies, interests, views, and beliefs. Physical traits are the most prominent responses; this allows the teacher to make the connection between the physical

FIGURE 4

Families of the periodic table jigsaw task card.

Task Instructions

1. You have been assigned to research a specific family of elements from the periodic table.
2. From the resources provided, read about your family and respond to the questions listed below in your science notebook.
3. Be prepared to share your findings in a short presentation to the class.
4. You will learn about the other families from the other groups.

Family Questions

1. Write down the name of the family of elements you have been assigned.
2. Name the elements in this family. (If you have transition metals, choose 6–8 elements since this family is particularly large compared to the other families).
3. Make a list of the properties the elements in this family share.
4. Think of a new name for this family based on the similar properties.
5. Write an address (description of location) for this family on the periodic table.
6. Give examples of uses of the elements in this family.
7. On your notecards, write the symbol and name for each element in this family. Be prepared to share the information from questions 1–6 in your presentation to the class.

traits that people in families share to the physical and chemical properties that elements in families share.

Through a jigsaw activity involving a large felt periodic table (see Figure 3), students learn more about the families and their properties. Put students into seven groups and assign each group a different family from the periodic table: alkali metals, alkaline Earth metals, transition metals, halogens, noble gases, lanthanides, and actinides. Hydrogen is not in a specific family, so the teacher can model the activity with hydrogen or assign it as an eighth group.

The students' task is to become experts on their assigned family by researching its chemical and physical properties, uses, location on the periodic table, and the elements in that family (see Figure 4). Each group prepares notecards with the symbols of the elements to place on the giant-size periodic table. Use index cards that come in assorted colors and assign one color per family, so students can clearly see the location on the giant-size periodic table.

The class then constructs the periodic table family by family by placing their prepared notecards on the giant-size periodic table using double-sided tape or Velcro (see Figure 4, p. 33). Groups present their findings and take notes during the presentations (see Figure 5 for a sample graphic organizer). After everyone has presented, give the students time to stand back and reflect on the periodic table they have constructed. Ask them what new patterns they observe and respond to any follow-up questions.

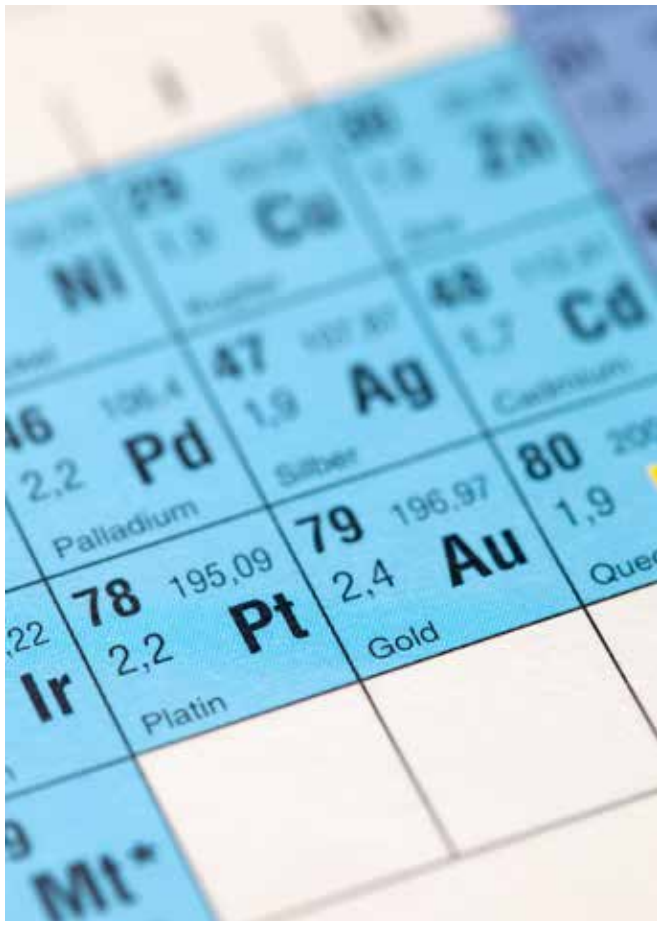


FIGURE 5

Sample graphic organizer.

Name of family	Properties of the elements in this family	New name to describe this family based on properties	Describe how to locate this family on the periodic table (like an address)	Elements that are in this family	Examples of uses of the elements in this family
alkali metals					
alkaline earth metals					
transition metals					
halogens					
noble gases					
lanthanides					
actinides					
hydrogen					

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

Standard

HS-PS1 Matter and Its Interactions

Performance Expectation

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

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.

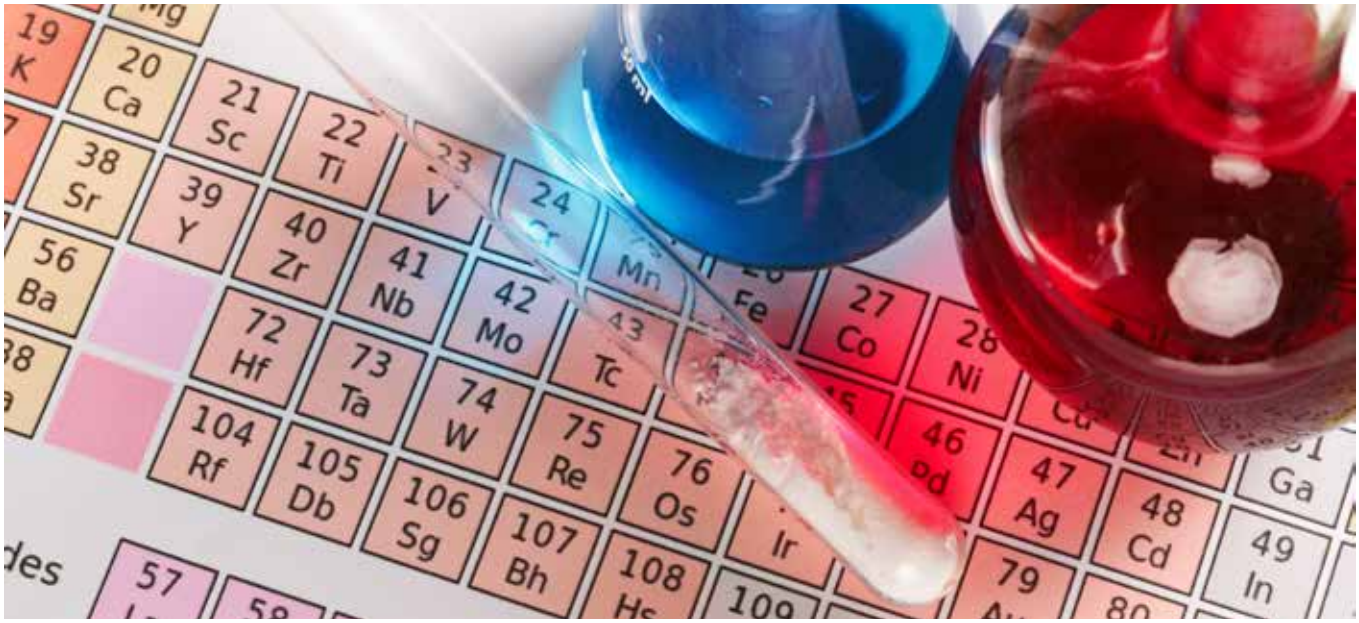
DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Constructing Explanations and Designing Solutions Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students construct the characteristics of the missing puzzle pieces citing the evidence from the pattern in the puzzle they established.
Obtaining, Evaluating, and Communicating Information Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.	Students research information about the families of the periodic table and present to the whole class about the chemical properties, location, and elements in their assigned family.
Disciplinary Core Idea	
PS.1A: 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 read and discuss the accomplishments of Mendeleev and his periodic table and how the elements were originally ordered by atomic weight and their properties (but later ordered by atomic number). In small groups, students summarize the properties of the elements in one of the families of the periodic table and present that information to the class.
Crosscutting Concept	
Patterns Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them. 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.	Students discover the patterns in a nontraditional puzzle and connect those experiences to Mendeleev's experience with looking for patterns among the elements.

Connecting to the *Common Core State Standards* (NGAC and CCSSO 2010)

ELA/Literacy

RST.9-10.2

Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.



Conclusion

After students have explored the history, structure, and organization of the periodic table, paying special attention to the element families and their properties, the teacher can move on to discuss the electron configuration. This subatomic particle guides the underlying pattern of the periodic table and strengthens understanding of the *NGSS* Disciplinary Core Idea PS1.A.

Because the goals of the puzzle lesson focus on the history of science and examining the information that Mendeleev had in his time, the discussion of electron configuration is not included. This and other periodic trends should guide the next series of lessons, since the students will have a foundation about the construction of the periodic table. Point out that we also know that the atomic number (number of protons) actually determines the order of the elements, but that in 1869 when Mendeleev announced the periodic law, "The elements, if arranged according to their atomic weights, exhibit an evident periodicity of properties," he only had information about their atomic weights.

Guide the students to the understanding that as scientists, they can only use the data they have at their disposal to construct their explanations. Stress that over time, as scientists contribute more discoveries and data (essentially the pieces of the puzzle), more understanding happens in regard to scientific phenomena. ■

ON THE WEB

Flinn Scientific's website dedicated to The Year of the Periodic Table: *https://nrpages.flinnsci.com/2019-year-of-the-periodic-table/*

NOVA's interactive periodic table: *www.pbs.org/wgbh/nova/physics/periodic-table.html*

Royal Society of Chemistry's interactive periodic table: *www.rsc.org/periodic-table*

Website about history of the periodic table: *www.mysteryofmatter.net/Periodic_Table.html*

Website for The International Year of the Periodic Table: *www.iypt2019.org*

Video by They Might Be Giants called "Meet the Elements:" *www.youtube.com/watch?v=d0zION8xjbM*

RESOURCES ABOUT MENDELEEV AND THE PERIODIC TABLE

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Cobb, C., and M.L. Fetterolf. 2005. *The joy of chemistry: The amazing science of familiar things*. Amherst, NY: Prometheus Books.

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