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Ideas for enhancing primary and high school science education

Did you Know?

The Air we Breathe

Every breath one takes contains about 50 million million (i.e., a 5 followed by 13 zeros) air particles, and also contains a few particles that have been breathed out by every person who has ever lived.

The Periodic Table as a Tool for Teaching the Nature of Science

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Abstract

Teaching the connectedness of relationships among elements in the Periodic Table is often an overwhelming task, and can result in shallow student understanding. This article contains a series of activities that evoke student prior knowledge about classification, leads them to discover periodicity and other relationships among the characteristics of elements, and extends their knowledge into other disciplines such as creative writing and art. The activities structure an effective learning environment because the foundation of understanding lies in the nature of science, utilizing process skills, content knowledge, and the history of science in order to teach conceptual understanding on multiple levels. The resultant understanding of the multi-dimensional patterns of the characteristics of the elements gained by engaging with these activities allows students to use the periodic table as a tool for predicting compounds and writing reaction equations. Based on the authors' experiences, 14- to 18-year-old students who have participated in these activities have been able to identify valence electrons effectively and correctly pair elements in ionic bonds. Given the formula, students were also adept in drawing dot diagrams of covalent compounds because they understood the meaning of the position of an element in the periodic table.

Introduction

According to the *National Science Education Standards* (National Research Council, 1996), students in Years 9-12 (14- to 18-year-olds) are expected to use the properties of matter to distinguish and separate one substance from another. Showing students the underlying features of the organization of the Periodic Table of Elements helps to accomplish this goal, but it is a daunting task and often not very meaningful to students. From a student perspective, understanding the multiple relationships shown in the Periodic Table can be overwhelming and abstract. Teachers can help students understand the patterns in the Periodic Table of Elements by using two strategies detailed in the following activities: Connecting familiar ways of sorting and categorizing to scientific organizing and guiding students to identify the way the Periodic Table of Elements is organized.

Object Organization Activity

Students often enter the classroom thinking that they do not understand science, but people naturally act in a scientific way by seeking out patterns and explanations. This activity begins by asking students to use their prior knowledge to classify some simple, everyday objects. The objects are paper cutouts with five different attributes, as shown in Table 1; shape, color, borders, size, and labels. Working in groups of 3 or 4, students are given a sample graphic organizer that includes an example using color as an organizing system (see Figure 1). The students are then asked to be creative and find four other ways to categorize these same objects and to illustrate their ideas on a graphic organizer.

Table 1
Attributes of Objects in the Object Organization Activity

Shape	Color	Border	Size	Labels
Rectangle	Blue	No border	Small	None
Rectangle	Red	Border	Large	X1
Rectangle	Yellow	Border	Large	Y1
Circle	Blue	No border	Small	Z1
Circle	Yellow	Border	Large	None
Circle	Red	Border	Large	X2
Square	Blue	Border	Small	Y2
Square	Yellow	Border	Small	Z2

Next, the groups take turns presenting their classification systems to the rest of the class. The student group work and reporting takes about 20 minutes. Some of the organizational systems suggested by students sort the objects into several equally-distributed groups, while others arrange the objects into one group that includes most of the objects and another group that includes the remaining few objects, as occurs when the objects are sorted on the basis of whether or not they have a border. At this point, the teacher asks the students: "Which organizational system is the most useful?" The pursuant discussion can be helpful in showing students why a scientist might want to organize the objects into more equally-distributed groups and conversely, why a scientist might want to isolate a member from a group. For example, scientists may want to classify objects into more equally-distributed groups when creating a key to use for identifying plants or animals so that identification can be done more quickly and efficiently. A scientist might want to isolate a member from a group to show its uniqueness, such as a duck-billed platypus classified as a mammal that lays eggs. At this point in the activity, it may be helpful to connect with the need for organization in everyday life by asking students to think about all of the ways they encounter categories. Students respond with examples such as the categorization of books in a library, compact disks at a music store, or clothing sizes.

After the object organization activity, students have a basis for understanding why organization is useful and how something can be organized in multiple ways using different attributes. Students who have participated in this activity have often defended their choice of an organizational system that distributed the objects equally by explaining their experiences with a dichotomous key in previous classes. As called for in the *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993), students are now guided from this concrete activity of organizing objects to the more abstract one of categorizing elements on cards.

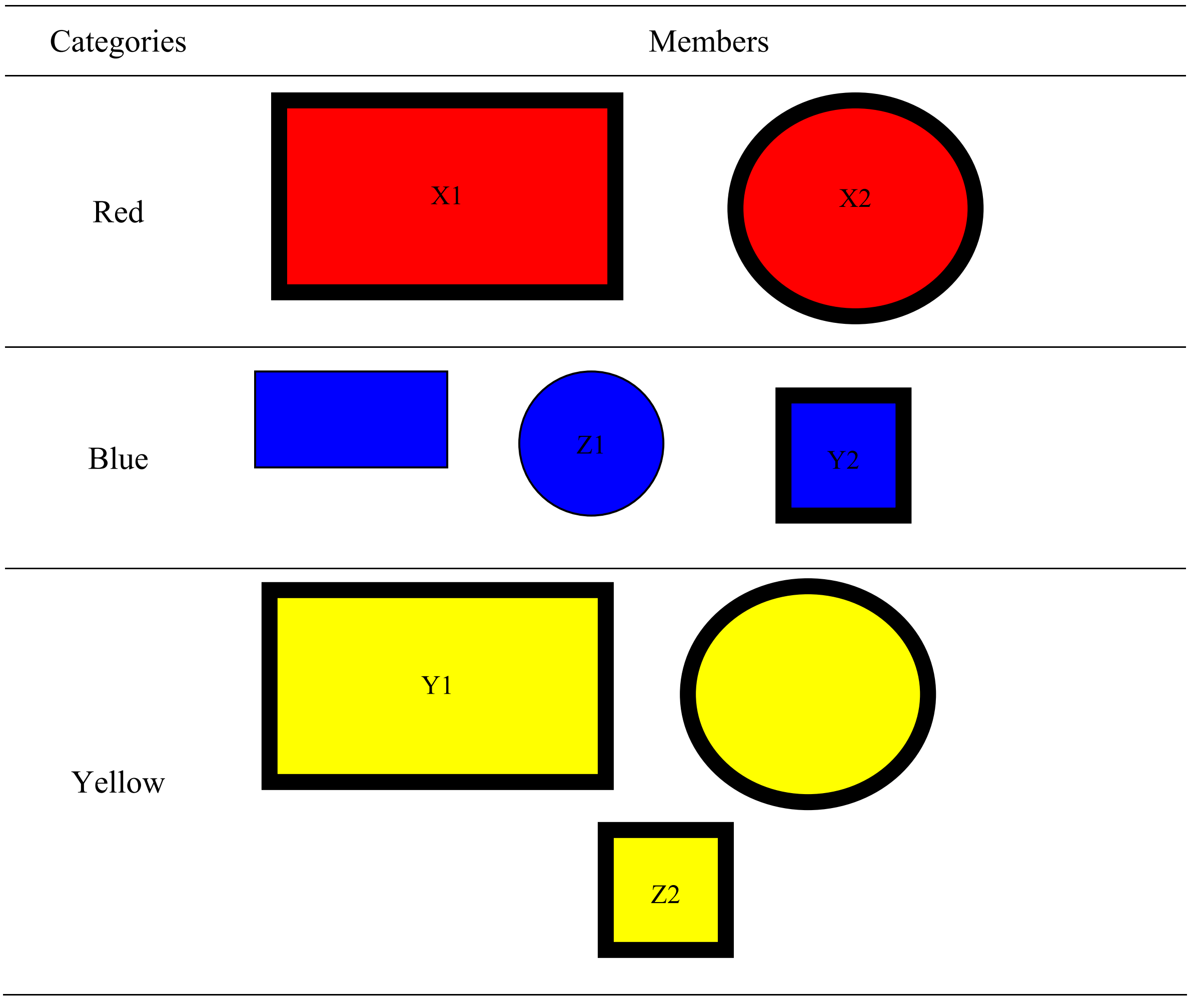

Figure 1. Sample graphic organizer for categorizing objects by color.

Element Organization Activity

To extend the concepts and skills about organization into science, each group of students is given an identical set of Element Cards (Figure 2)[1], with each card displaying information for one of the chemical elements from atomic number 3 to atomic number 20. This information comprises symbol, name, atomic number, atomic radius, number of valence electrons, and the general physical properties for each element. Each group is asked to decide on one organizational system for their deck of cards. While the organizational system may involve grouping, it may also involve the ordering of the cards to reflect some trend or pattern. This exercise takes about 20 minutes.

Each group reports their organizational choice to the entire class, with these results contributing to a summary, on the board, of possible Element Card arrangements such as those shown in Table 2. If necessary, the teacher can probe students for additional suggestions. The teacher then asks students which of the organizational schemes are based in nature (i.e., are science-based) and which are based on human constructs such as alphabetical order (i.e., are not science-based). Some questions that can initiate student discussions are:

- What might be some criteria that would make one system more useful than another?
- Are some systems more useful than others?

This activity also gives students an opportunity to recognize that the Periodic Table of Elements is guided by patterns found in nature, rather than being merely a human construct built for convenience. By the end of the discussion, students who grouped their cards alphabetically instead of by using a scientific characteristic may say that they have changed their minds about how they want to organize the information. Students may feel it would be easier to look up the names of the elements if they were alphabetized, but see the value of organizing the elements by something more standard, like atomic radius.

Li
Lithium
Atomic Number: 3
Atomic Radius: 152 picometers
Valence Electrons: 1
Properties: Soft, silvery, lowest density metal, reacts quickly with halogens and with water.

Figure 2. Example of an Element Card.

Table 2
Possible Element Card Arrangements

Feature	System	Type of feature
Name	Alphabetical (A-Z) by name of element	Not science-based
Symbol	Alphabetical (A-Z) by first letter of symbol	Not science-based
Number of letters in symbol	One letter or two letters	Not science-based
Atomic number	3-20	Science-based
Valence number	Group with 1 valence electron, group with 2 valence electrons, group with 3 valence electrons, and so on	Science-based
Atomic radius	Ascending or descending atomic radius	Science-based
Properties	Groups with similar properties	Science-based

Process and Content Connected

The progression of ideas involved in these activities helps to bring together ideas of science content and scientific processes in developing knowledge while transitioning from concrete to abstract knowledge. Knowing how processes in science are used can foster scientific skills. However, knowing why the processes in science are used in particular circumstances illustrates an understanding of the nature of science. Helping students to separate process and content in the activities allows them to progress to an understanding of the nature of science (Peters, 2006). To illustrate this distinction, students are asked to construct a T-chart (Figure 3) that lists the scientific content learned in the lesson and the scientific processes used in the lesson.

Periodic Table Activities

Scientific Content	Scientific Processes
Periodicity of atomic radius	Recognizing Patterns
Periodicity of valence	Classifying elements
Groups have similar properties	Sorting, ordering, sequencing, and organizing chemicals according to different properties

Figure 3. T-Chart indicating scientific content and processes.

Connections to the Nature of Science

To connect the discussion to the nature of science, students are asked:

- If the grouping systems are equally valued for their usefulness, how would a scientist choose which system to follow?
- How might scientists agree on which system to follow?

This discussion allows students to think about the decisions that scientists must make in constructing a common organization system to help with scientific understanding. Teaching factual scientific knowledge without teaching how the knowledge can be acquired rarely allows students to think above the recall level (Duschl, 1990). When students are required to only memorize facts of the Periodic Table of Elements, they are not given the opportunity to think more critically about why the Periodic Table of Elements has come to be known in its current form. A method for incorporating higher-level thinking skills to teach the structure and properties of matter is to have students understand why the Periodic Table is organized the way it is and to be able to use it as a tool to look up information about the elements (Sterling, 1996). When students understand the principles that scientists use to construct knowledge, they have the power to construct their own knowledge (Brooks & Brooks, 1999). During this portion of the discussion, students may express the need for the scientific community to agree on a standard so that they can communicate amongst each other, which also emphasizes the social nature of science.

Seeking Multiple Patterns

After the foregoing discussions, the teacher tells the class that there is one known organizational system for chemical elements that allows for many different properties to be grouped together and that the following activity will help them discover that system. The teacher asks the students to line up the cards in order of atomic number. When students have the cards lined up, they look for other patterns that occur due to arrangement of the elements by atomic number. Students recognize several patterns: Valence number is increasing by one until it gets to eight, and then begins again; atomic radius decreases, then increases, and begins to decrease again; or properties of the elements also form a repeating pattern. The atomic radius is included because of its repeating, but counter-intuitive, pattern of getting smaller as the atomic number increases across a row. If there is time and your students would benefit, they can speculate why this might be the case.

Students begin to realize that by ordering the elements by atomic number, other types of organization systems develop naturally, reinforcing the idea that patterns occur in nature and it is the role of scientists to find and describe these patterns. At this point in the lesson, it is important that the teacher connects the idea of repeating patterns to the term *periodic*. Periodicity is then extended to everyday life by prompting students to give examples of things in their lives that form repeating patterns. They often respond with examples such as meal times, the days of the week, or the months of the year. If a student doesn't bring it up, the teacher can ask for an alternate name for classes, such as periods. Students attend first period, then second period, then third period, and so on. Each day the pattern repeats again, just as it does in the Periodic Table of Elements. Often students spontaneously have an "ah-ha" moment where they realize that they attend the same periods each day and each day the periods repeat. Many students say: "I never knew why they called them periods until now." Because information from students' everyday lives is connected to abstract scientific information, the name Periodic Table of Elements has much more meaning.

Students compare their line of cards to the organization and structure of the Periodic Table. They then arrange their cards in the same way as the Periodic Table. The teacher prompts the students to observe that the Periodic Table has patterns both horizontally across the table in each row and vertically in each column. The Periodic Table of Elements is structured to give a great deal of information if the observer understands what to look for. Since students construct knowledge about the underlying patterns that are formed when the elements are put into order by increasing atomic number, they have access to the Periodic Table of Elements as a tool to look up information about elemental features.

Mendeleev's Process

These activities can also be extended to teach students about the history of science. Teachers can discuss with students the process used by Mendeleev, either after the activity or when card sorting is introduced, or ask students to search the literature for Mendeleev's process themselves. When students know more about the process of card sorting that Mendeleev used in developing his system for the Periodic Table, they can have a deeper understanding of how historical factors play a role in the construction of scientific knowledge.

There were several versions of the Table of Elements before Dmitri Mendeleev proposed his adaptation. Being an enthusiastic card player, Mendeleev wrote the 63 elements known in his time on separate cards and repeatedly laid them out to discover patterns. He realized that when he ordered the cards by atomic mass (atomic number was not known in 1869), the chemical and physical properties of the elements formed a repeating pattern. From his version of the Periodic Table, Mendeleev predicted the existence of several undiscovered elements, which were subsequently found during his lifetime. The scientific community continues to use Mendeleev's basic idea for the Periodic Table of Elements, except that the elements are ordered by atomic number rather than by atomic mass.

Assessment and Extension

For assessment, students might be asked to explain in writing why the Periodic Table of Elements was given this name, to describe how the Periodic Table is organized, and to identify both horizontal and vertical patterns. In order to assess student understanding of the history of science, students can be asked to use a library search to develop a sequence of events that describe the development of the current Periodic Table of Elements. Emphasis for this task should be placed on the understanding that ideas in science are not created in isolation, but rather are built from existing scientific information. Appendix A contains suggestions for extensions to this activity.

According to Duschl (1990), when students are given only factual knowledge, two major conflicts occur. The first is that students do not feel responsible for constructing knowledge, because the teacher is feeding them facts. Students feel that the information that constitutes knowledge is fixed and only available to authorities such as teachers, so they passively wait for their education. Another conflict occurs when students are given scientific facts as if they were in the final form, and then told that ideas in science change over time. When students are given the opportunity to find out how scientific knowledge is gained as well as the knowledge itself, they are empowered to construct knowledge actively. As a result of participating in this series of activities, students are exposed to both the factual knowledge that is provided by the Periodic Table of Elements and the scientific processes and habits of mind that are required to produce scientific knowledge.

The Periodic Table of Elements has been a useful tool for identifying and predicting chemical properties for over 100 years, yet student understanding of the trends in the Periodic Table rarely rise above recall. Teaching the history and rationale behind the development of the Periodic Table can help students grasp the intricate relationships between the elements as well as aid their understanding of the nature of science.

Note

[1]Additional Element Cards may be obtained by contacting the corresponding author.

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Appendix A: Possible Activity Extensions

Write a Summary Paragraph
Reflecting on the information you learned today, write a paragraph using the following words to explain how the Periodic Table of Elements is organized: Organization, scientific, elements, periodic, valence electrons, atomic number, properties, atomic radius.

Write an Editorial Supporting Mendeleev's Prediction of Missing Elements
Before the predicted elements were found, Mendeleev's hypothesis that elements needed to follow a pattern was controversial. Many scientists did not think that organizing elements by property was sufficient evidence to predict unknown elements. Suppose you lived during that time period. Write an editorial article for the local newspaper supporting Mendeleev's predictions.

Make a Periodic Table of Food
Given 12 different dried foods such as beans, rice, and pasta, create a Periodic Table of Food. Be sure to organize your food groups in as many ways as possible. You can even find the "atomic mass" of each food by using a balance to measure the average mass of one "atom" of each type of food. In this case, an atom is the conventionally

recognized singular part of the food item. For the purpose of this activity, a broken piece of macaroni is no longer an atom.

Investigate the Properties That are Common to Each Group of Elements
The Periodic Table of Elements organizes elements in columns called groups or families. Use library materials to research the common features of each group of the Periodic Table. How could you include this information in today's activity? [Students might be expected to predict the general properties of elements not included in their card sort (e.g., that rubidium would be very reactive in water and that the reactivity for elements increases as the atomic number increases within a column. Students could then make cards to extend their current deck to higher atomic numbers.]

Investigate how Alternate Perspectives Might Make Other Forms of the Periodic Table Plausible
(*Teacher's Note*: See a periodic table shaped as a spiral at http://www.periodicspiral.com/ and an unusually-shaped periodic table designed for use by physicists at http://www.meta-synthesis.com/webbook/35_pt/pt.html#af .)

Teaching Ideas

Science stories, teaching techniques, demonstrations, activities, and other ideas

A Small-Scale Bed of Nails

The construction of a traditional bed of nails, suitable for lying, sitting, or standing on, is time-consuming. As an alternative, a smaller bed of nails may be constructed to support an inflated balloon. Use a 3-inch x 3-inch board to support a 5 x 5 matrix of nails about 0.5 inches apart. To prevent splintering, pre-drill holes for the nails with a diameter slightly less than that of the nails. Place the balloon on the nails and a wooden platform on the balloon. The platform can be supported by four longer vertical nails. The balloon will support several kilograms of mass placed on the platform before breaking.

Source: Ramsey, G. P. (2004). Building a better bed of nails demonstration. *The Physics Teacher*, *42*, 438-439.

Bad Science

Exposure to "bad science," in the form of scientific blunders and abuses, can be useful in facilitating students' understanding of the nature of science. For example, students might be invited to search for information about, and discuss, the following topics:

- *Phrenology and craniology*. Here, the measurements of a person's facial features and skull are equated with innate personality characteristics and behaviours, such as criminal temperament and intelligence. During the latter half of the 18^{th} century, the British used this discredited concept to justify regarding African and Irish people as inferior races, because the jaw measurements of people in the latter two groups were considered to be more similar to that of monkeys, apes, or Cro-Magnon humanoids than the Anglo-Saxon people of Europe. Flaws in the concept include incomplete attention to disconfirming evidence and the use of circular reasoning.
- *DDT*. The insecticidal properties of DDT were discovered during the 1930s, and this chemical was widely used in agricultural settings, during World War II to reduce troop exposure to disease-carrying insects, and in communities in the United States to eradicate mosquitoes and biting flies. However, many pest species developed resistance to it and many beneficial insect populations were destroyed, creating a situation that was even worse than before DDT was used. The chemical also spread through food webs causing, for example, a marked decline in birds of prey. DDT was banned in 1972.