Nonconventional Methods in Teaching Matter, Atoms, Molecules, & the Periodic Table For Nonmajor Students

Abour A. Cherif Gerald E. Adams Charles E. Cannon

Instructional strategies that allow the integration of a variety of approaches such as hands-on activities, visualization, writing, demonstrations, role play, and guided inquiry are important in bridging the gap between concrete and abstract understanding of scientific concepts and principles among students. The following are a few of the instructional strategies that we have used in classes (from middle school through introductory college courses) and have found to be useful in helping nonscience majors better understand the nature of matter, atoms, molecules, the periodic table, and other related topics.

The understanding of matter and its atomic properties is fundamental to the study of most biological and physical sciences in their present forms. For example, in biology, a basic understanding of chemistry (the study of matter and the changes it undergoes) is fundamental to understanding how cells, organisms, and ecosystems work. It is also important in understanding physiology, genetics, evolution, and the origin of life on the planet Earth. Therefore, students need to learn the atomic basis of matter and the periodic properties of the elements, in order for them to succeed in understanding most scientific concepts presented in any science class. At the same time, it is not at all obvious that matter consists of invisible particles called *molecules*, and that these molecules are made of even smaller, invisible particles called *atoms*, and that atoms and subatomic particles are even further removed from direct experience. Likewise, it is not at all obvious how the list of elements that we call the periodic table has any sense of organization at all. Students, especially those who prefer the sensing mode of learning and perceiving (Schroeder 1993), might have difficulty with these concepts, as a result of both the abstract nature of atomic theory and the extremely formal pattern represented by the periodic table[1]. Therefore, we attempt to find ways to help our students understand these concepts, through methods like visualization of atomic and subatomic structures, writing stories or short essays about atomic interactions that form molecules, and by designing games and maps to navigate the periodic table. We have collected, designed and modified activities based on our experiences with our students who are specializing in areas of arts, media and communication.

The common thread among all the learning activities and ideas in this paper is the integration of hands-on activities and writing. This integration is the tool for interpretation, learning, expressing thoughts and ideas, and of demonstrating the understanding of abstract topics. Randy Moore (1994) has urged teachers to ask their students to write, because writing is a powerful tool, not only for putting down what is already in their heads, but also for helping them to think, to discover, to develop and to organize ideas, and to learn effectively. In 1986, "a survey conducted by the National Assessment of Educational Progress (NAEP) of 95,000 high school seniors showed that 76% of the students could not write an imaginative essay, 80% could not write a persuasive letter, and 62% wrote unsatisfactory prose" (Moore 1994, p. 290). On the average, "high school students in the United States write fewer than 500 words per semester, while students in England write about 1,000 words per week" (Moore 1994, p. 287).

Why Do We Believe There Are Such Things as Atoms?

Classical experiments that led to the development of given scientific concepts and principles we hold today, such as the principle that atoms are the building blocks of matter, can be powerful learning tools for the illustration of the tenets of science. We have found these experiments, either in descriptive form or as actual demonstrations in the classroom, to be powerful learning tools helping students conceptualize the invisible particles that we call atoms. Following are a few of the classroom demonstrations that are direct analogies to the classical experiments of Ernest Rutherford and his assistant, Hans Geiger. These demonstrations led to Rutherford's model of an atom with a tiny nucleus containing practically all the mass of the atom, with the rest of the atom's volume being empty space

[1] In a learning environment, effective instructors are always able to recognize students who prefer the "sensing" mode of learning and perceiving (a practice-to-theory route through highly structured instruction), and those who prefer the "intuitive" mode (theory-to-practice approach through open-ended interaction), and can balance their teaching styles accordingly (Schroeder 1993).

Abour Cherif, Ph.D., teaches biology and science education; **Gerald Adams**, Ph.D., teaches geology and environment; and **Charles Cannon**, Ph.D., is the Chairperson of the Department of Science and Mathematics, and teaches chemistry, all at Columbia College, Chicago, IL 60605.

through which subatomic particles can easily pass.

If matter is made of atoms, then there should be spaces between the atoms through which smaller particles might pass. If matter filled all the space, Rutherford reasoned, the particles would have no chance of getting through. With this idea in mind, Rutherford and Geiger (in 1908) bombarded a thin metal foil with a beam of fast-moving particles (positively charged "**alpha**" particles from a radioactive source material). Specifically, they used a gold leaf beaten to a thinness of only one fifty-thousandth of an inch (which was still at least 2,000 atoms thick). In contrast to their expectations, Rutherford and Geiger observed that almost all of the particles (approximately 95%) went right through the seemingly solid foil without being deflected at all, and amazingly, only a few (approximately 5%) of the particles were sharply deflected; some even bounced back in the direction from which they came.

To provide a sound interpretation of the gold-foil experiment, Rutherford hypothesized that the solid material was made of atoms, with most of the "solid" part being concentrated in a central region, the atom's nucleus. In addition, he proposed an arrangement of the positive and negative parts of the atom with all the positively charged matter and almost all of the mass also concentrated in the nucleus.

> *When an alpha particle, which is positively charged, approached the positively charged nucleus, it was strongly repelled and therefore deflected. Since only a few alpha particles were deflected, Rutherford concluded that the nucleus must occupy only a tiny fraction of the total volume of an atom. Most of the particles passed right through, because most of an atom was empty space. The space outside the nucleus isn't completely empty, however. It was here that Rutherford placed the negatively charged electrons. He concluded that electrons had so little mass that they were no match for the alpha bullets. It would be analogous to a mouse trying to stop the charge of a bull elephant.* (Hill & Kolb 1995, p. 61)

According to many scientists and science historians, Rutherford's acceptable interpretation of the results of the gold-foil experiment was revolutionary indeed.

> *He postulated that all the positive charge and nearly all the mass of an atom are concentrated in a tiny, tiny nucleus. The negatively charged electrons have almost no mass, yet they occupy nearly all the volume of an atom. To picture Rutherford's model, visualize a sphere as big as a giant indoor football stadium. The nucleus at the middle of the sphere is as small as a pea but weighs several million tons. A few flies flitting here and there throughout the sphere represent the electrons.*
> (Hill & Kolb 1995, pp. 61–62)

Activity #1: Using Analogy To Understand the Concept of Atoms

One approach in helping your students through the concept of atoms and the Rutherford and Geiger experiment involves a simple, yet effective, analogy. Ask your students to imagine taking a garden hose and spraying water at a solid wall. Ask them how much water would get through the wall and how much would bounce back, and discuss why this is the case.

Then ask your students what would happen if holes were cut in half the surface of the wall, and then water was sprayed through the hose at that wall. Ask how much water, in this case, would go through, and how much would bounce back. Again, discuss why this is the case (hopefully, the collective conclusion will be that half the water will go through and half will bounce back). You might also give a second example, with a different fraction of holes to solid wall (or perhaps a percentage of holes to solid wall), to reinforce the direct relationship between the percentage of holes and the percentage of water getting through or bouncing back.

Now, ask your students what they think the wall would be like if they sprayed water at it, and 95% went through the wall and only 5% bounced back. They may predict that the wall is mostly holes, or even that the holes make up 95% of the wall, with only 5% of the wall being solid. They might even try to think of some real material that would work this way (a window screen is a good possibility, but they may think of others). At this point, the Rutherford and Geiger experiment can be introduced, and the students can be asked to interpret their result, that is, that 95% of the beam of particles goes through the thin foil, and 5% bounces back. The analogy between the water and the beam of particles, and the foil and the wall, should be clear to them, and they will probably conclude that the foil is actually almost 95% "holes" with only 5% "solid" material, just as Rutherford and Geiger did. In the Rutherford and Geiger experiment, the "solid" part is interpreted as the nuclei of the atoms in the foil, and the "holes" are interpreted as mostly empty space, but containing tiny particles (electrons) revolving around the nuclei in orbits, like planets, which orbit through mostly empty space around the sun.[2]

Activity #2: Experimenting with Aluminum Foil, a Geiger Counter, and a Low-Level Radioactive Source

Another possibility for simulating this experiment is to use a Geiger counter and a low-level, alpha-emitting radioactive source, such as monazite, carnotite, fergusonite, thorite, zircon, allanite, columbite-tantalite, or commercially prepared non-mineral sources. (Note: many primary and secondary schools are prohibited by state or local safety regulations from having such materials on the premises, so check on the regulations before trying to obtain them.) Monazite and fergusonite are more radioactive, and should be stored in a lead-lined container, or packed in lots of paper. They can be obtained from scientific catalogs (such as Sargent-Welch, VWR Scientific, or Science Kit & Boreal Laboratories) in forms that are not harmful, or borrowed from the physics, chemistry or geology departments of local colleges or universities. Aluminum foil may be used as the thin metal foil.

First, to demonstrate that the foil has no perceptible holes, take a piece of the foil and a six-inch length of plastic pipe (like the pipe you can get in a hardware store for indoor plumbing, around one inch in diameter), and seal one end of the pipe with the foil. You may need to use a little petroleum jelly to form the seal and a strong rubber band to hold the foil in place. Now, using the guided inquiry approach (Cherif 1988, 1993), ask your students: "What do you think would happen if we try to: 1) run water through the tube; 2) blow air through the tube; and 3) shine light through the tube?" Write the students' predictions on the blackboard and then discuss them one by one. Then allow the students to perform the actual experiments. Finally, discuss the results of

[2] Incidentally, this kind of activity, called a "thought experiment," is a method used by many scientists to help them visualize some abstract concept. Many famous thought experiments have led to important discoveries in science by helping us to understand the results of real, physical experiments. In the fifth century B.C., Greek philosopher Leucippus and his pupil Democritus used thought experiments to understand that matter is made of tiny particles called atoms.

the experiments in light of their original predictions.[3]

Now, introduce the class to the Geiger counter as a tool for detecting and counting radioactive particles. Then take the radioactive material (low-level, alpha source) and detect the radioactivity coming from it using the Geiger counter. After having established the baseline level of radioactivity, ask your students: "What do you predict will happen to the radioactivity if we try to pass it through the tube or if we cover the material completely with foil?" Again, write the students' predictions on the blackboard and then discuss them—one by one, and use the students' ideas as a way of finding out what they are thinking.

Once there is no more discussion of students' predictions, put the radioactive source in the tube or wrap it up in the aluminum foil (let your students do this, so they are sure it is completely wrapped). Then, let the students use the Geiger counter to discover what actually happens and to compare this to their earlier predictions. Most of them will be surprised that almost all the radioactivity "leaks out." Then, ask them to explain their observations, and if their prediction was incorrect, have them explain why.

It is important for students to go beyond the experiment and the interpretation of its result. They need to understand the significant contributions this and other related experiments have made in our understanding of how the natural and the artificial world work. On the basis of intuition and curiosity about what the atom is made of, along with a recognition that matter could be studied by bombarding it with fast-moving particles, Rutherford became one of the first two scientists who tore apart the atom to discover its secrets (the other scientist was Ernest Orlando Lawrence). By aiming subatomic particles (positively charged "alpha" particles) at metal targets to split open their atoms, Rutherford turned radioactivity from a phenomenon into a tool. He was the first scientist to change one element (nitrogen) into another (oxygen), and in 1919, he became the first to bring about a human-made nuclear reaction.

[3] The following six questions were proposed in Cherif's Guided Inquiry Approach (1988, 1993): (a) What do you think will happen if. . . . ? (b) What actually happened? (c) How did it happen? (d) Why did this happen? (e) How can we find out which of these hypotheses is the most reasonable? and (f) How can you relate the investigation to your daily life?

For elementary, middle school, and secondary students we would recommend having the teachers do all of the handling of the radioactive source, while explaining to the students why it is relatively safe to do so. For example, alpha particles have very little penetrating power and external exposure generally causes little more than mild skin irritation.

Nuts & Bolts for Atoms & Compounds in the Classroom

In recent years, common hardware (nuts and bolts) has become popular again as a learning tool, especially for microchemistry, at levels from upper elementary school through college. The idea of using nuts and bolts as teaching tools is not new. It was suggested and used by a few college and school instructors, such as Larry Strong and Wilmer Stratton (then at Earlham College), as far back as 25 years ago. After a period of abandonment, the idea was revitalized by creative instructors such as Carlson and Carlson (1990). Today, nuts and bolts have been used to help students differentiate between atoms and molecules, to simulate chemical reactions and the formation of compounds, and to write simple chemical reactions, as well as to disassemble chemical compounds, made from nuts and bolts, and to write the reactions that must have taken place to make the compounds in the first place. The method has the following advantages:

1. The materials used are cheap and nonhazardous.
2. Students can easily obtain the materials to practice and study at home.
3. The materials are visible and tangible, and can be easily manipulated, so that experiments can be readily accomplished by almost all students, and the results examined by tactile and visual senses.

(Teachers should be aware, however, that for students with coordination or fine-motor skill problems, this kind of activity can be more frustrating than a more verbal or abstract approach.)

Numerous examples of chemistry activities in recent literature use nuts and bolts as effective analogies to explain atomic/molecular theory, but several good starting activities can be found in *Microchemistry: Instructor's Manual*, by Carlson and Carlson (1990), published by Educational Systems Associates, Inc. You can use nuts and bolts, which can be found in various sizes and shapes and are made of different materials, usually metals (e.g. long bolts, short bolts, hex nuts, square nuts, wing nuts, etc.) to represent different kinds of atoms. Instructors can easily teach and students can easily learn the differences between the various kinds of "atoms" and "elements," and how to make "molecules" and "compounds" by assembling compatible nuts and bolts. The students can also learn to use symbols instead of words to describe the makeup of various compounds by combining a number of atoms in different ways. Nuts and bolts can also be used to teach how to write and balance simple chemical equations, as illustrated in the following activities.

Activity #1: Making Elements, Compounds & Molecules

To familiarize the students with nuts and bolts and what they can do with them, first challenge them to make some compounds and molecules using nuts and bolts. After giving students enough time to try on their own, ask them: "If we assume that some atoms are represented with nuts or bolts as shown in Table 1, then can we make the following molecules using nuts and bolts?

- Water (H_2O)
- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Sodium chloride ($NaCl$)
- Iron oxide (FeO)
- Magnesium oxide (MgO)
- Silver iodide (AgI)
- Bicarbonate (HCO_3)
- Sulfate (SO_4)
- Sulfite (SO_3)
- Sodium hydroxide ($NaOH$), etc."

This activity will reinforce the students' understanding of *element* (matter that is made up of only one kind of atom), *compound* (matter that is made up of two or more different kinds of atoms that are linked together), and *molecule* (matter that is made up of two or more atoms combined and that acts as a single particle).

Activity #2: Making & Balancing Simple Chemical Equations

Nuts and bolts can be used to illustrate making and balancing simple and carefully defined chemical equations or reactions (Carlson & Carlson 1990). They can also be used to reinforce students' understanding of the ideas behind making and balancing chemical equations. A chemical reaction takes place when the bonds between atoms

Table 1. Examples of a few atoms and how they could be represented with nuts or bolts.

Atom	*Letter Symbol*	*Nut/Bolt*	*Nut/Bolt Symbol*
Hydrogen	H	Short Bolt	Sb
Carbon	C	Long Bolt	Lb
Sodium	Na	Square Long Bolt	SLb
Iron	Fe	Square Short Bolt	SSb
Magnesium	Mg	Hex Short Bolt	HSb
Sulfur	S	Hex Long Bolt	HLb
Silver	Ag	Philips Short Bolt	PSb
Nitrogen	N	Philips Long Bolt	PLb
Oxygen	O	Hex Nut	Hn
Chlorine	Cl	Wing Nut	Wn
Iodide	I	Square Nut	Sn
**		Colored Hex Nut*	CHn
**		Colored Wing Nut*	CWn
**		Colored Square Nut*	CSn

*Since there is a limited number of different kinds of nuts and bolts, you could spray paint, for example, hex, wing, and square nuts and use them as additional different kinds of atoms.
**Instructors can fill these spaces with elements of their choice.

or group of atoms are broken and rearranged to form new substances. Since matter cannot be created or destroyed in chemical reactions, then the number of atoms in the reactants (the chemicals that take part in the reaction) will stay the same in the new products (the chemicals that the reaction produces). Because of this, when equations (symbols and formulas of the chemicals that take part in chemical reactions) are written down, they show that the number of atoms on one side of an equation is the same as on the other. This illustrates that atoms are not made or destroyed in chemical reactions.

As an illustration, ask students to imagine compounds made of long bolts (Lb), short bolts (Sb), wing nuts (Wn), and hex nuts (Hn) where the short bolts can only hold one nut and the long bolts can hold two. The following exchange reaction (not balanced) can be written to describe an interchange of nuts between the two kinds of bolts:

$$LbHn_2 + SbWn = LbWn_2 + SbHn$$

Students can be asked to balance the equation (physically and manually) by disassembling the compounds on the left and assembling the compounds on the right without having any parts left over. Give them three or four "molecules" of each compound on the left so that they can see how many they can disassemble and reassemble successfully into the compounds on the right. They will have some of the compounds on the left that they will not be able to disassemble and reassemble; you could get them to talk about limiting reactants by seeing which ones are used up and which ones are left over.

Activities such as these can also be used to reinforce students' understanding of chemical reactions, the substance(s) that takes part in a chemical reaction (reactant), and the substance(s) that is produced in a chemical reaction (product). Students will see that a chemical reaction produces chemical change and a chemical change produces new products.

The activity can also be used to replicate chemical equations. For example, students can be given a number of equations and then be asked to replicate them using nuts and bolts:

$$2\,Na + O_2 + H_2 \text{———} 2\,NaOH$$

$$H_2SO_4 + BACL_2 \text{———} 2HCL + BaSO_4$$

$$4HCl + 2MnO_2 \text{———} 2MnCl_2 + 2H_2O_2$$

$$NaOH + HCl \text{———} NaCl + H_2O$$

Furthermore, nuts and bolts can also be used to illustrate and/or reinforce the understanding of some types of chemical reactions such as combination (the direct joining of two or more elements or simple compounds), decomposition (the breakdown of a compound into simpler elements or compounds), and replacement reaction (the substitution of one element for another in a compound).

Activity #3: Learning by Writing

When writing assignments are complemented with specific instruction about how to use writing as a tool to learn science, writing can be one of the best tools in learning a given scientific concept or principle (Moore 1992, 1994). One example of a writing activity to accompany this physical activity is to have students describe in paragraph form what a chemical reaction is and how the reaction took place. They should include the starting substances (reactants), all the steps of disassembling the starting substances and assembling the products, and a description of the products (new substance). They should also include why and how scientists write formulas and equations, and how they balance equations.

Another writing activity could require students to use their imaginations to create other combinations of nuts and bolts to form different compounds from the ones that they have seen, and to describe reactions in which their new compounds might participate. This kind of abstract thinking will assist them in understanding the abstract nature of real chemical reactions, while still allowing them to check on their predictions by physically assembling the nuts and bolts in simple chemical reactions. We would recommend, however, that teachers explain to the students that while abstract thinking is necessary to understand the nature of chemical reactions, in the real world the reactions themselves and the combination in definite proportions are not abstract. They are strictly governed real phenomena.

The Periodic Table: Our Small, Beautiful Town

When we visualize an element on the periodic chart we have more potential to understand the characteristics of this element and its relationship to the neighboring elements and the elements in its own group (vertical column) and its own period (horizontal row). In helping students to do this, the periodic table can be viewed as a town with streets (the vertical columns) and avenues (the horizontal rows), neighborhoods (alkali metals, alkali earths, etc.), genders (metals and nonmetals), and even a suburb or two (the lanthanides [rare earths] and actinides [transuranium]). As in any town, there will be those people who will get along with and interact with others, and those who are self-centered, who interact only with themselves or a very limited number of people. This town can even be thought of as ethnically structured, meaning that any one ethnic group can be easily identified by the neighborhood in which the people live. For these activities, the classroom should have a periodic table, preferably one that has illustrations of what each element looks like in its pure state, as well as references and books such as *The New York Public Library Science Desk Reference* by Schroeder (1995), *The Periodic Kingdom* by Atkins (1995), *Exploring Chemical Elements and Their Compounds* by Heiserman (1992), *The Elements* by Cox (1989), and *The Elements* by Emsley (1989).[4]

Activity #1: Invitation To Visit the Element City

The objective of this activity is to reinforce the understanding of how and why elements are arranged in the periodic table the way they are. For example, all the metals are located at one end of the periodic table while all the nonmetals are at the other end. Also, for example, all the elements in a given group behave similarly in chemical reactions and they change gradually as we go down the group. Students are assigned randomly to become a particular element in the periodic table. Then they are asked to write a general description of their "town" and a detailed description of their "neighborhood" in a letter to be sent to a friend who has never been there. The descriptions must be comprehensive, clear, and should include the relationships that exist between the "neighborhood" and the people (elements) who live there. The letter should also include the writer's address, with complete and clear directions on how to find the address when coming from out of town.

Examples of addresses

12th Avenue and 4th Street
Northwest, Transition Metals Neighborhood.
Just four blocks west of Halogens Neighborhood.
Element City, Planet Earth.

3rd Avenue and 5th Street
Southeast, Alkaline Earth Metals Neighborhood.
Just one block west of Alkali Metals and one block east of Transition Metals Neighborhood.
Element City, Planet Earth.

17th Avenue and 4th Street
West, Nonmetals Neighborhood.
Just one block east of Noble Gases and four blocks west of Transition Metals Neighborhood.
Element City, Planet Earth.

Students are also asked to introduce a couple of individuals (elements) of their choice to this friend in their letters. The introduction should include a description of how to find these two individuals (elements), using what they know about the individuals' chemical and physical characteristics, and individuals' neighbors and friends (see Tables 2 and 3). While this activity sounds simple, students soon discover that it is more difficult than it appears, especially for those students who are already having difficulty using city maps to find their way around. The students need to understand the factual knowledge about the periodic table: its elements, and the characteristics of the elements. They also need to discover relationships, to organize information, and to communicate their knowledge and understanding in written form. This activity involves a lot of thinking, simply because writing demands that the students develop, organize and communicate their ideas (Moore 1994).

Activity #2: Help Find the Missing Element

This activity is a follow up to the previous activity, "Invitation To Visit The Element City." Students can be asked to go either to the police station or to the local TV station, and to report that a given person (element) of the "city" is missing. The police officer (or TV reporter) needs the following information in order to launch a search (or put the story on the air):

1. The person's exact address (element's position). Include: cross streets, which part of the city the address is in, and how far away it is from a landmark in the city. For example, the concentration of elements in gas form, the concentration of most strongly acidic elements, the concentration of most strongly basic elements, or the location of most semimetal elements in the periodic table (see Clark 1994).
2. Chemical/physical description; the phase of the elements, behavior oxides, relative density, relative melting and boiling points, atomic number, atomic mass, etc. See Table 3 for a few examples, and Clark (1994), Heiserman (1992), and Emsley (1989) for more examples and information.
3. With which kinds of people (elements) does the missing person (element) like to interact? Which ones does he or she avoid? Is this person (element) one of those elements that are generally found as pairs of atoms bound together and are called diatomic elements? Diatomic elements include hydrogen (H_2), oxygen (O_2), nitrogen (N_2), chlorine (Cl_2), bromine (Br_2), and iodine (I_2).
4. The missing person (element) is assumed to be kidnapped. Therefore, what is the chemical, biological, or other significance of this missing person that explains why he/she was kidnapped? (For possible reasons, see Tables 4, 5 & 6.)
5. Date of birth (date of the discovery of the given element), See Table 5 for a few examples, and Heiserman (1992), Cox (1989), and Emsley (1989) for more examples and information.
6. Parents (person or persons who discovered the element, if they are available to the students. See Heiserman (1992), Cox (1989), and Emsley (1989) as references).
7. Number of brothers or sisters (isotopes) if they exist. Isotope is an alternative form of an element having the same atomic number but a different atomic mass due to the different number of neutrons present in the nucleus. See Table 3

[4] The Periodic Table of Elements by Gelest, Inc. is a good one to be made available for the students in this activity. More recently, Science Import of Sillery, Quebec, Canada, has designed a very colorful and illustrative Periodic System of Elements that comes in binder size (8½" × 11"), poster size (38" × 25"), and wall size (90" × 60"). The Time-Life publication, "Matter" (Lapp 1963), has such illustrations and is readily obtainable from libraries or the publishers. Also, Vegetarian Times in Oak Park, Illinois, produced "Periodic Table of Vegetables" (18½ × 29½) and "Periodic Table of Fruits & Nuts" (18½ × 29½). These two periodic tables are useful in the classrooms. Finally, companies such as Arbor Scientific, Fisher Scientific, Flinn Scientific, Learning Things Inc. Nasco, Science Import, and Nurnberg Scientific all carry these kinds of illustrated periodic tables of the elements.

Table 2. The valence electrons and the number of energy shells of selected elements in the periodic table.

Element	*Atomic Number*	*Valence Electrons*	*Energy Shells & Their electrons*	*Period*	*Group*	*Belongs To*
Aluminum (Al)	13	3	2, 8, 3	3	13	Boron/carbon families
Argon (Ar)	18	8	2, 8, 8	3	18	Inert gases
Barium (Ba)	56	2	2, 8, 18, 18, 8, 2	6	2	Alkali earth metals
Bromine (Br)	35	7	2, 8, 18, 7	4	17	Halogens
Calcium (Ca)	20	2	2, 8, 8, 2	4	2	Alkali earth metals
Carbon (C)	6	4	2, 4	2	14	Boron/carbon families
Chlorine (Cl)	17	7	2, 8, 7	3	17	Halogens
Chromium (Cr)	24	4	2, 8, 13, 1	4	6	Transition metals
Cobalt (Co)	27	3	2, 8, 15, 2	4	9	Transition metals
Copper (Cu)	29	1	2, 8, 18, 1	4	11	Transition metals
Fluorine (F)	9	7	2, 7	2	17	Halogens
Germanium (Ge)	32	4	2, 8, 19, 4	4	14	Boron/carbon families
Gold (Au)	79	1	2, 8, 18, 32, 18, 1	6	11	Transition metals
Helium (He)	2	2	2	1	18	Inert gases
Iron (Fe)	26	2	2, 8, 14, 2	4	8	Transition metals
Lead (Pb)	82	4	2, 8, 18, 32, 18, 4	6	14	Transition metals
Lithium (Li)	3	1	2, 1	2	1	Alkali metals
Magnesium (Mg)	12	2	2, 8, 2	3	2	Alkali earth metals
Mercury (Hg)	80	2	2, 8, 18, 32, 18, 2	6	12	Transition metals
Neon (Ne)	10	8	2, 8	2	18	Inert gases
Nickel (Ni)	28	2	2, 8, 16, 2	4	10	Transition metals
Nitrogen (N)	7	5	2, 5	2	15	Nitrogen/oxygen families
Oxygen (O)	8	6	2, 6	2	16	Nitrogen/oxygen families
Platinum (Pt)	78	4	2, 8, 18, 32, 17, 1	6	10	Transition Metals
Potassium (K)	19	1	2, 8, 8, 1	4	1	Alkali metals
Silicon (Si)	14	4	2, 8, 4	3	14	Boron/carbon families
Silver (Ag)	47	1	2, 8, 18, 18, 1	5	11	Transition metals
Sodium (Na)	11	1	2, 8, 1	3	1	Alkali metals
Sulfur (S)	16	6	2, 8, 6	3	16	Nitrogen/oxygen families
Titanium (Ti)	22	4	2, 8, 10, 2	4	4	Transition metals
Tungsten (W)	74	6	2, 8, 18, 32, 12, 2	6	6	Transition metals
Uranium (U)	92	6	2, 8, 18, 32, 21, 9, 2	7	—	Actinide, rare-earth element
Zinc (Zn)	30	2	2, 8, 18, 2	4	12	Transition metals

For further information about selected properties and uses of elements teachers can look at, for example, Hill & Kolb (1995), Maton et al. (1993), Chisholm & Johnson (1993), Heiserman (1992), Emsley (1989), Cox (1989), and Lapp (1963).

for a few examples, and Heiserman (1992), and Emsley (1989) for more examples and information.

8. The valence electron (the number of electrons in the outermost energy level of an atom), and the number of energy levels of a given atom are also useful information that can be included in this activity. See Table 2 for some examples.

Activity #3: Design ID Cards for Individuals (Elements) of the City of the Periodic Table

Again, for this activity you need to make available for the students a periodic table that has illustrations of what each element looks like in its pure state as well as copies of Tables 2, 3, 4, 5 & 6. Have your students design an ID card that an element might carry around to identify him/herself. The cards should carry as much information as possible, including pictures (from a periodic table that has illustrations of what each element looks like in its pure state), address, neighborhood, gender (metal, nonmetal or metalloid), number of brothers or sisters (isotopes) if they exist, and known neighborhoods (such as inert gases, halogens, nitrogen and oxygen families, boron and carbon families, rare-earth elements, etc.). The valence electrons and the number of energy levels of a given atom can also be included in this activity, as well as behavior of oxide, relative density, and relative melting and boiling points (see Tables 2 and 3 for some examples).

Plain Periodic Table Learning Activities

The following research activities can be adapted, at various levels of complexity, for students from middle school through college (and even graduate study). They all require the use of a plain periodic table with only the pattern showing, and none of the actual elements as seen in Figure 1. The following activities show how periodic tables can be designed for special purposes, such as research about the elements and their uses. To help your students in their library research for these activities, give each student a copy of Tables 2, 3, 4 and 5 to use as starting point.

Activity #1: Reinforcing the Understanding of Various Elements in the Periodic Table

A plain periodic table can be used to reinforce the understanding of various elements. For example, students are divided into groups of four, then each group is asked to randomly select one of the following questions, do library

Table 3. Behavior of oxides, relative density, melting and boiling points of some elements in the periodic table.

Element	*Behavior of Oxides*	*Phases of the Elements*	*Relative Density*	*Melting Point (°C)*	*Boiling Point (°C)*	*No. of Isotopes*
Aluminum (Al)	Equal Relative Strength	Solid-Metal	2.70	660.37	2467	11
Barium (Ba)	Strongly Basic	Solid-Metal	3.51	729	1805	35
Boron (B)	Weakly Acidic	Solid-Semimetal**	2.34	2079	2550*	6
Bromine (Br)	Strongly Acidic	Liquid-Nonmetal	7.59	−7.2	58.78	28
Calcium (Ca)	Strongly Basic	Solid-Metal	1.54	842	1494	16
Carbon (C)	Weakly Acidic	Solid-Nonmetal	2.62	3550	4827	7
Chlorine (Cl)	Strongly Acidic	Gas-Nonmetal	3.214	−100.98	−34	13
Chromium (Cr)	Weakly Acidic	Solid-Metal	7.20	1863	2672	13
Cobalt (Co)	Equal Relative Strength	Solid-Metal	8.90	1495	2928	17
Copper (Cu)	Weakly Basic	Solid-Metal	1.54	1085	2563	18
Germanium (Ge)	Equal Relative Strength	Solid-Semimetal	5.47	938	2834	24
Gold (Au)	Equal Relative Strength	Solid-Metal	19.3	1064	2808	39
Hydrogen (H)	Weakly Acidic	Gas-Nonmetal	0.089	−255.34	−252.87	3
Iodine (I)	Strongly Acidic	Solid-Nonmetal	4.92	113.5	184.35	37
Iron (Fe)	Equal Relative Strength	Solid-Metal	7.86	1538	2762	16
Lead (Pb)	Equal Relative Strength	Solid-Metal	11.34	327.5	1750	41
Lithium (Li)	Strongly Basic	Solid-Metal	0.53	181	1342	5
Magnesium (Mg)	Strongly Basic	Solid-Metal	1.74	650	1090	12
Manganese (Mn)	Strongly Basic	Solid-Metal	7.20	1246	2062	15
Mercury (Hg)	Weakly Basic	Liquid-Metal	13.6	−38.8	357	37
Molybdenum (Mo)	Weakly Acidic	Solid-Metal	10.20	2623	4639	23
Nickel (Ni)	Weakly Basic	Solid-Metal	8.90	1455	2914	14
Nitrogen (N)	Strongly Acidic	Gas-Nonmetal	1.25	−209.86	−195.8	8
Phosphorus (P)	Weakly Acidic	Solid-Metal	1.82	44.1	280	10
Platinum (Pt)	Weakly Basic	Solid-Metal	21.45	1769	3827	36
Potassium (K)	Strongly Basic	Solid-Metal	0.86	63.7	759	18
Radium (Ra)	Strongly Basic	Solid-Metal	5.0	700	1140	25
Rubidium (Rb)	Strongly Basic	Solid-Metal	1.48	39.5	688	30
Silicon (Si)	Equal Relative Strength	Solid-Semimetal**	2.33	1410	2355	11
Silver (Ag)	Equal Relative Strength	Solid-Metal	10.50	962	2163	46
Sodium (Na)	Strongly Basic	Solid-Metal	0.97	97.8	88.3	14
Sulfur (S)	Strongly Acidic	Solid-Metal	2.07	112.8	4.6	11
Titanium (Ti)	Equal Relative Strength	Solid-Metal	4.50	1660	3287	13
Tungsten (W)	Weakly Acidic	Solid-Metal	19.35	3422	5655	29
Uranium (U)	Equal Relative Strength	Solid-Metal	18.68	1135	4134	17
Zinc (Zn)	Equal Relative Strength	Solid-Metal	7.14	419.6	907	23

*This is the sublimation point of the element.
**Semimetal is an element that has properties of both metals and nonmetals.
***For further information, see Clark (1994), Heiserman (1992), Cox (1989), Emsley (1989), or Periodic Table of the Elements published by Sargent-Welch Scientific Company (catalog #S.18805-50).

research, and then answer the question in the plain periodic table:

a) Identify those elements that are found in liquid form at room temperature, and then place them in the plain periodic table.
b) Identify those elements that are called the "Noble Metals" and then place them in the plain periodic table. Explain why they are called "Noble Metals."
c) Identify the chemical element that is the most abundant in the universe and the chemical element that is most abundant on Earth, and then place them in the plain periodic table.
d) Some elements are very difficult to extract from monazite ore, where they occur. These elements are called the "Rare Earth Elements." Identify a few of them and place them in the plain periodic table.
e) Identify those elements that are the most abundant in the Earth's crust and then place them in the plain periodic table.
f) Identify elements that have some of the properties of metals and some of nonmetals (metalloids) and then place them in the plain periodic table. See Table 4.
g) Fill in those elements that commonly participate in ionically bonded substances and elements which commonly form covalent bonds.
h) Identify those elements that are weakly acidic, those that are weakly basic, and those that have equal relative basic/acidic strength.
i) Fill in those elements that are strongly basic and those that are strongly acidic (see Table 3). Most of the strongly basic elements are found on one side while most of the strongly acidic elements are found near the other side of the periodic table.

Elements can be classified by their electronegativity—the ease with which they gain (or retain) electrons to form ions. A clue is

Table 4. Selected properties and uses of some elements in the periodic table.

Element	*Atomic Number*	*Natural State & Selected Properties*	*Some Common Uses of the Element*
Aluminum (Al)	13	Solid, soft, light, silvery-white metal	Food wrapping; power lines; toothpaste tubes; airplane wings; etc.
Argon (Ar)	18	Colorless, odorless, tasteless, noble gas	Light bulbs; fluorescent tubes
Barium (Ba)	56	Solid, soft, silvery-white metal	Fireworks; medicine; paints; glass making
Bromine (Br)	35	Liquid, reddish brown (Br_2)	Compounds; medicine; photography; dyes
Calcium (Ca)	20	Solid, silvery white metal	Making steel; producing uranium; cement, plaster & plasterboard
Carbon (C)	6	Solid, soft black (graphite) or hard, brilliant crystal (diamond)	Diamond; glass cutting; graphite; electric contacts; pencils
Chlorine (Cl)	17	Greenish yellow, gas (Cl_2)	Water purifier; swimming pools; disinfectants; bleaching agent
Chromium (Cr)	24	Solid, hard, crystalline, steel-gray metal	Coating steel and parts, used in making pigments
Cobalt (Co)	27	Solid, hard, ductile, lustrous blue metal	Magnets; blue color in glass and ceramics, heat resistant tools
Copper (Cu)	29	Solid, ductile, light reddish brown metal	Electric wiring; pipes and plumbing; motors
Fluorine (F)	9	Corrosive, pungent, pale yellow gas (F_2)	Compounds; food pans; toothpaste; etching glass; refrigerants
Germanium (Ge)	32	Solid, grayish-white metal	Transistors
Gold (Au)	79	Solid, yellow, malleable metal	Alloy*; jewelry; dentistry; coins & base for money system
Helium (He)	2	Colorless, odorless, tasteless, inert gas	Airships; balloons; by deep-sea divers
Iron (Fe)	26	Solid, silvery white, ductile, malleable	Manufacturing steel; building materials; crane hooks; anchor chains
Lead (Pb)	82	Solid, bluish white, soft, heavy metal	Car batteries; roofing; x-ray machines
Lithium (Li)	3	Solid, silvery white, soft, light metal	Air conditioners; medicine; metallurgy
Magnesium (Mg)	12	Solid, silvery white, ductile light metal	Auto and space vehicle parts, flash bulbs; photography; medicine
Mercury (Hg)	80	Liquid, silvery white, heavy metal	Thermometers; tooth filling; modern blue-hued street lights
Neon (Ne)	10	Colorless, odorless, tasteless, inert gas	Advertisement signs; fluorescent lighting
Nickel (Ni)	28	Solid, hard, silvery white, ductile metal	Alloys; catalyst; electroplating; batteries; coins; jewelry; plating
Nitrogen (N)	7	Colorless, odorless, tasteless, inert gas (N_2)	Making ammonia; its compounds include anesthetic, TNT; fertilizers
Oxygen (O)	8	Colorless, odorless, tasteless, (O_2)	Hospitals; sewage plants
Platinum (Pt)	78	Solid, heavy, soft, silver-white metal	Catalyst; electrical contacts; jewelry; hinging human bones; delicate instruments; weights/measures
Potassium (K)	19	Solid, soft, waxy, silvery white, metal	Compounds; glass, soap, dyes, fertilizer; medicine; photography
Silicon (Si)	14	Solid, lustrous gray	Chips for electronic circuits, etc.
Silver (Ag)	47	Solid, silvery white, ductile metal	Alloys*; jewelry; coinage; mirror backing; electrical conductor
Sodium (Na)	11	Solid, silvery white, soft metal	Sodium vapor lamps; soap; table salt; lye
Sulfur (S)	16	Brittle solid, odorless, tasteless, yellow (S_8)	Making rubber; medicines; fungicides, etc.
Tungsten (W)	74	Solid, heavy, steel-gray to white metal	Alloys*; tools; lamp filaments
Titanium (Ti)	22	Solid, shiny, dark-gray metal	Aircraft wings; bright paints; heart pacemakers; jewelry
Uranium (U)	92	Solid, silvery, ductile radioactive metal	Generating neutrons for chain reactions in a nuclear reactor
Zinc (Zn)	30	Solid, bluish-silver, ductile metal	Prevention rust; alloys; batteries; paints; medicines

*An alloy is a mixture of two or more elements, at least one of which is a metal; it has its own metallic properties.
**For further information about selected properties and uses of elements, see, for example, Hill & Kolb (1995); Horton et al. (1993); Maton et al. (1993); Chisholm & Johnson (1993); Heiserman (1992); Cox (1989); or Lapp (1963).

Table 5. Chemical elements essential for human life.

Name of Element	*Atomic Mass*	*Date of Discovery*	*Function*
Carbon (C)	12.011	ancient	These elements are present throughout all living organisms.
Hydrogen (H)	1.008	1766	
Oxygen (O)	15.9994	1774	
Nitrogen (N)	14.0067	1772	
Boron (B)	10.81	1808	Aids in the use of Ca, P, and Mg
Calcium (Ca)*	20.08	1808	Necessary for growth of teeth and bones
Chlorine (Cl)*	35.453	1744	Necessary for maintaining salt balance in body fluid
Chromium (Cr)	51.996	1797	Aids in carbohydrate metabolism
Cobalt (Co)	58.9332	1774	Component of vitamin B12
Copper (Cu)	63.546	ancient	Necessary to maintain blood chemistry
Fluorine (F)	18.99840	1771	Aids in the development of teeth and bones
Iodine (I)	126.9045	1811	Necessary for thyroid function
Iron (Fe)	55.847	ancient	Necessary for oxygen-carrying ability of blood
Magnesium (Mg)*	24.305	1755	Necessary for bones, teeth, and muscle and nerve action
Manganese (Mn)	24.305	1774	Necessary for carbohydrate metabolism and bone formation
Molybdenum (Mo)	95.94	1778	Component of enzymes necessary for metabolism
Nickel (Ni)	558.71	1751	Aids in the use of Fe and Cu
Phosphorus (P)*	30.97376	1669	Necessary for growth of bones and teeth; present in DNA & RNA
Potassium (K)	39.09	1807	Component of body fluids; necessary for nerve action
Selenium (Se)	78.96	1817	Aids in vitamin E action and fat metabolism
Silicon (Si)	28.086	1823	Helps form connective tissue and bone
Sodium (Na)*	22.9898	1807	Component of body fluids; necessary for nerve and muscle action
Sulfur (S)*	32.06	ancient	Component of proteins; necessary for blood clotting
Zinc (Zn)	65.38	1746	Necessary for growth, healing, and overall health

*Other than C, H, O, and N which are present in all foods, listed elements vary in their distribution in different foods. Those marked with an asterisk are *macronutrients*, essential in the diet at more than 100 mg/day; the rest, other than C, H, O, and N, are *micronutrients*, essential at 15 mg or less per day. For more information, see Hill & Kolb (1995), Maton et al. (1993); Chisholm & Johnson (1993); Cox (1989); Lapp (1963).

Table 6. Chemical elements are found in soil and used in plant growth.

Element	*Atomic No.*	*The Importance of The Elements to Plant Growth*
Nitrogen (N)	7	Essential nutrients used in large quantities, called macronutrients.
Phosphorus (P)	15	
Potassium (K)	19	
Calcium (Ca)	20	
Magnesium (Mg)	12	
Sulfur (S)	16	
Oxygen (O)	8	
Carbon (C)	6	
Hydrogen (H)	1	
Iron (Fe)	26	Essential nutrients used in small quantities, called micronutrients.
Manganese (Mn)	25	
Copper (Cu)	29	
Zinc (Zn)	30	
Boron (B)	5	
Molybdenum (Mo)	42	Beneficial nutrients that are not essential.
Sodium (Na)	11	
Chlorine (Cl)	17	
Cobalt (Co)	27	Beneficial nutrients to some plants but not essential.
Iodine (I)	53	

*For more information see, for example, *A Book About Soils* by Ortloff & Raymore (1962).

given by the behavior of their oxides. Those of the highly electronegative sulfur and chlorine are strongly acidic, whereas those of the alkali metals (sodium, etc.) are strongly basic. (Clark 1994, p. 149)

Activity #2: Reinforcing Understanding of the Elements Essential to Life

A plain periodic table with only the pattern showing and none of the actual elements can be used to reinforce the understanding of the elements essential for human life. In addition to C, H, O, and N, which are present in all foods, other elements are essential in the diet at more than 100 mg/day and are called *macronutrients*. Yet, some other elements are essential at 15 mg or less per day and are called *micronutrients* (see Table 5). Fill in those macronutrient and micronutrient elements that are essential in the human diet, and write a short description of how the body uses one macronutrient and one micronutrient element. You can also ask students to fill in those elements that are often used in the manufacture of medicines such as Barium (Ba), Bromine (Br), Potassium (K), and Zinc (Zn) (see Table 4).

Students can also be asked to fill in those elements that are found in soil and used in plant growth and development. Which of these elements are essential nutrients and are used in large quantities (macronutrients), and which are used in small quantities (micronutrients)? Which of these elements are beneficial but are not essential for plant growth? See Table 6 and Ortloff & Raymore (1962) for more information.

Activity #3: Reinforcing Understanding of Some of the Elements Essential in Industry

Give each student a copy of a plain periodic table with only the pattern showing, and none of the actual elements as seen in Figure 1. Then ask the students to find, through library research, only some of the restricted groups of elements, for example:

1. Fill in all those elements used in fireworks, including those used in the container, the propellant charge, and the coloring agents.
2. Fill in elements that are obtained in the U.S. primarily by importing them from other countries, along with the country (or countries) of origin.
3. Fill in elements that are often used in producing paints.
4. Fill in elements that are often used in the manufacture of electrical parts, transistors, and electrical wires.
5. Fill in elements that are often used in medicine.
6. Fill in elements that are often used in glass making.

In this activity, teachers could also introduce the concept of strategic minerals:

> *Strategic minerals are minerals essential to the national defense—the supply of which a country uses but cannot produce itself. 33% to 50% of the 80 minerals used by industry could be classed as strategic minerals. Wealthy countries such as the United States, stockpile these minerals to avoid any crippling effect on their economy or military strength if political circumstances were to cut off their supplies. The United States, for instance, stockpiles bauxite (14 1/2 million tons), manganese (2.2 million tons), chromium (1.8 million tons), tin (185,000 tons), cobalt (19,000 tons), tantalum (635 tons), palladium (1.25 million troy ounces), and platinum (453,000 troy ounces).(The Handy Science Answer Book 1994, 114)*

Activity #4: Bridging Science to Nonscience Disciplines

As extensions of this activity and to bridge science to nonscience disciplines, students might be asked to investigate how selected elements are used (industrial history), or the dollar value of U.S. imports of strategic elements and the impact of these imports on the balance of trade in the U.S. (economics). An even more advanced activity is to find those countries to which the U.S. gives foreign aid, or those countries where major U.S. companies have multinational corporate partners, and to try to correlate these lists with the list of countries from which the U.S. imports strategic elements (geography, economics and political science).

Trips Within Chemical Compounds

Activity #1: A Short Trip Within a Chemical Compound

1. Select eight compounds from those that are made up of more than two different elements, such as: sodium hydroxide or lye ($NaOH$), carbonic acid (H_2CO_3), sucrose or table sugar ($C_{12}H_{22}O_{11}$), magnesium sulfate or epsom salts ($MgSO_4$), sulfuric acid (H_2SO_4), sodium bicarbonate or baking soda ($NaHCO_3$), potassium carbonate (K_2CO_3), sodium dihydrogen phosphate (NaH_2PO_4), etc.
2. Write the chosen compounds on the blackboard in either chemical formula or written words (not both).
3. Ask each student to select two different compounds from the list, and write them down in both chemical formula and written words.
4. Ask each student to take two short trips, one into each compound he or she selected from the list. The students have to describe their trips within the compound in one written page (for each trip). The description should include:

a. Number of elements in each compound
b. Names of the elements in each compound
c. The number of atoms of each element within the compound
d. The total number of atoms in each compound
e. The kinds and the numbers of the chemical bonds in each compound
f. The basic arrangement of atoms in the compound.

Encourage the students to be creative and to free their imaginations while they write their short trips within the compounds.

Activity #2: People Meeting People

Chemical compounds can also be considered as people meeting each other for the first time. Ask each student to write down eight different chemical compounds and to consider these compounds as different people. Then ask them what could happen when some of these "people" compounds encounter and interact with each other. Students have to answer this question in both chemical equation and written formats.

From our own experiences with art, media and communication students as well as with teachers in in-service workshops, participants respond positively and creatively to this short writing assignment. However, for safety reasons, instructors should make sure the students do not literally (in the lab or elsewhere) affect an interaction between some of these pairs; the reactions could be violent. If interaction between some of these pairs is tried, it must be in the lab and only after proper precautions are followed.

Summary

Matter, atoms, molecules and the periodic table of the elements are essential in understanding basic chemistry which in turn is fundamental to other scientific disciplines, including modern biology. The preceding activities are just a few of the strategies we have used in helping college level nonscience majors, student teachers, inservice workshop participants, and selected middle school and high school students to understand the nature of matter, atoms, molecules and the periodic table. The strategies integrate a variety of approaches, including hands-on activities, visualization, writing, demonstrations, role play, and guided inquiry, among others. We want especially to emphasize the importance of writing in science learning, both because of its effectiveness, and because writing is a skill our students need to develop in all areas of study. Incorporating innovative writing assignments in the learning process not only enhances students' learning and understanding, but is also fun for both students and teachers.

We have tried to create the kind of environment that encourages students to engage in constructing meaning and making sense of what they learn and do in the class. This type of learning is known as the constructivist learning model and is often used to activate constructive meaning, facilitating a number of desired goals, and enhancing students' long-term understanding of the learning concepts and principles.

While we have no quantitative data regarding measures of effectiveness at the present time, we observe that our students have increased enthusiasm for these abstract subjects and show (anecdotally at least) better recall of the basic information and an enhanced ability to apply the information to different situations. We would appreciate feedback from any interested colleagues on the success or failure of any of these ideas in actual classroom application.

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