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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.

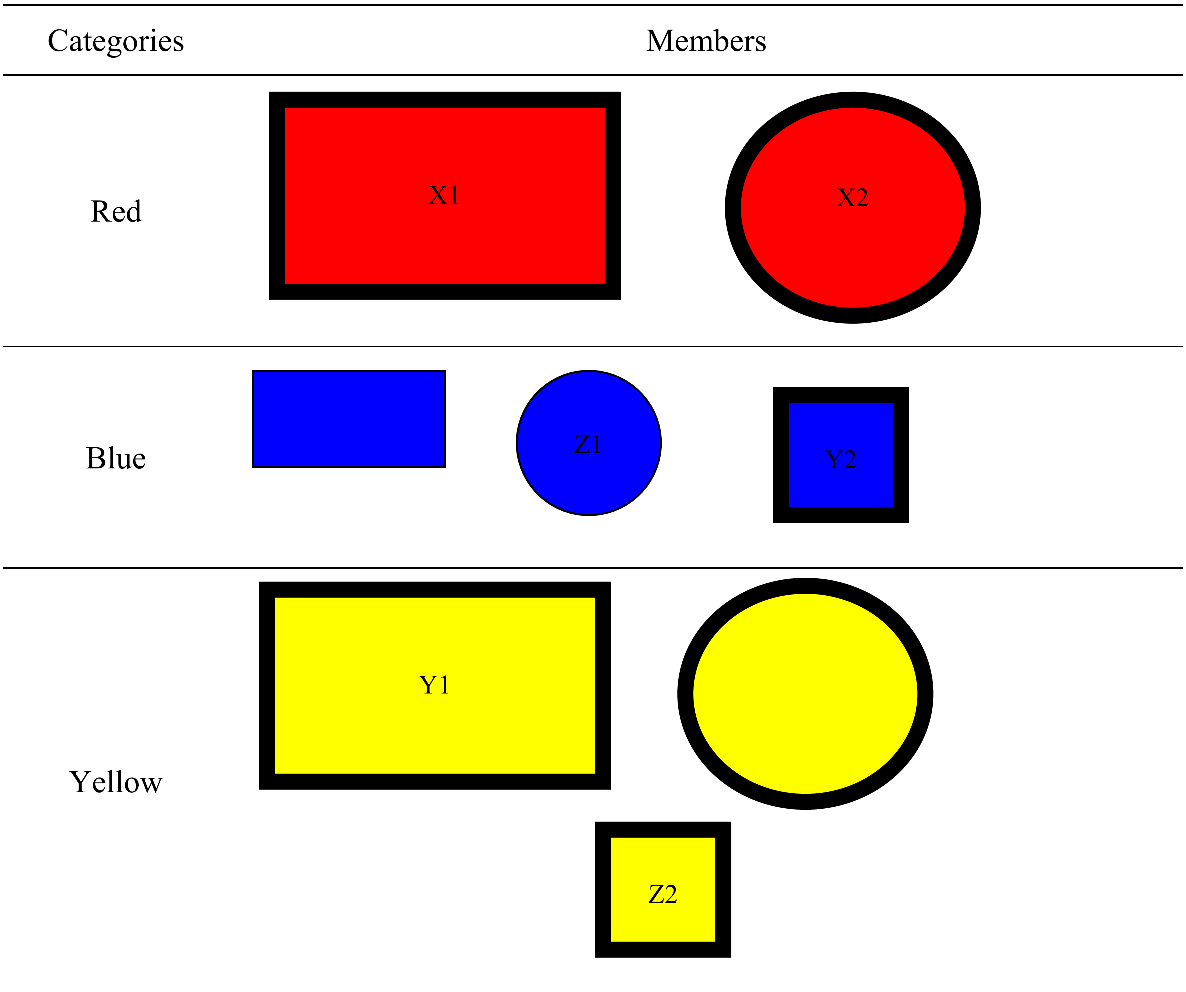

Figure 1. Sample graphic organizer for categorizing objects by color.

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 18th 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.

- *Tuskegee syphilis*. In the early 1930s, when treatment options for syphilis were suspect and largely unavailable, doctors and scientists began studying African Americans suffering from the affliction in Macon County, Alabama, United States of America, which included the town of Tuskegee. By the 1950s, it was well-known that the disease could be cured using readily-available penicillin. However, the study, requiring observation of the cause of the disease, continued without this treatment being offered, despite unnecessary suffering and even considerable deaths as a result of complications. It wasn't until 1972 that this research ended abruptly after a newspaper reporter brought national attention to the injustice.
- *Malaleuca*. The introduction of an exotic plant, animal, or microorganism to a location, whether inadvertently or intentionally, can have calamitous consequences. This is the case with the malaleuca, a large tree native to Australia and New Guinea that was introduced to the southeastern United States of America to drain the wetlands before it was realized that these wetlands are vital for the maintenance of healthy ecosystems. Malaleuca now grows relatively uncontrolled, displacing native species and altering hydrological patterns.
- *Tobacco*. Immediately after large tobacco companies began sponsoring research into the effects of their products in the early 1920s, the high toxicity and dangerous consequences associated with consuming tobacco products became clear. However, the tobacco industry not only concealed and denied the existence of such evidence, but misused science in an attempt to demonstrate the efficacy of its products and even increased the nicotine content of its products to prey on an unsuspecting public.

Source: Sadler, T. D., & Zeidler, D. L. (2003). Teaching "bad science." *The Science Teacher*, *70*(9), 36-40.

Reading Questions

Rather than a reading quiz, reading questions may be used to encourage students to read prior to coming to a class (Henderson & Rosenthal, 2006; Offerdahl, Baldwin, Elfring, Vierling, & Ziegler, 2008). After reading, each student electronically submits a single question to the instructor by some due time prior to the class. The reading can lay the foundation for in-class activities and discussions of more complex ideas, and the questions can reveal students' novice ideas about a topic and thereby guide instruction. All submitted questions and, time permitting, a teacher response to at least some of them, might be made available to all students via, for example, a web log. The questions students submit may even be graded (e.g., 3 points for showing deep and sustained thought, 2 points for evidence of significant thought, 1 point for no significant thought, and 0 points for nothing turned in by the deadline).

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A Rationale for Mnemonics

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The technique of using mnemonics, a Greek word meaning "to remember," had its origin with the ancients as they used this strategy to help them recall the dialogue in their many plays. The use of these memory devices continued unabated in most cultures until the Guttenberg printing press provided a viable way to more reliably communicate. Still, even with centuries of technological advances, memory strategies persist.

In his book *How the Brain Learns*, David Sousa (1995) delineates two types of mnemonics that are appropriate for students. The first device is rhyming. "Rhymes are simple and effective ways to remember rules and patterns. They work because if you forget part of the rhyme, or get part of it wrong, the words lose their rhyme or rhythm and signal an error" (p.64). In addition, Lowery (1998) addresses the importance of patterns as he contends that humans are pattern seekers and pattern recognizers and we use these repeating events as a means of resolving problems, creating plans, and crafting the answers to things.

The second type of memory device is referred to as reduction mnemonics and is most commonly observed in the use of letters to represent a phrase, order, or list, such as HOMES for the names of the Great Lakes or the following sentence as a reminder of the proper procedure for diluting an acid: "Do what you oughter, add acid to water."

Beyond the creation and use of mnemonics as an aid to memory, it is noteworthy for teachers to understand something about how the brain stores and retrieves information. Sousa (1996) contends that the human brain stores information by similarity and retrieves it by difference. For example, words like latitude and longitude are stored together because they are similar in spelling, sound, and concept and this similarity leads to confusion. A mnemonic is often the key to retrieving one word in the pair and, obviously, if one is retrieved correctly the meaning of the other is then easier to conjure.

The underlying message for teachers is to consider the plausibility that a number of the mental stumbling blocks students experience on a daily basis might be the result of a storage issue in the brain. If this is a reasonable assumption, then the infusion of teacher-created mnemonics or, better yet, student-created memory tactics, would be an advantageous addition to the delivery of instruction. Just as an aside, does anyone know a way to remember how to spell mnemonics?

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Two Equations of Life

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For a curriculum to be implemented by teachers, they have to be involved in choosing, adapting, and developing it (Glickman, Garden, & Ross-Garden, 2001). This report focuses on one part of an innovative science unit planned, designed, and implemented by the teacher-researcher in a fifth-grade science classroom in Turkey. The main objective was to have the students understand photosynthesis and respiration as two imperative processes in life.

Teaching for understanding. One of the primary objectives of teaching is to provide understandable instruction (American Association for the Advancement of Science [AAAS], 1993, 1999). Teachers should try to find innovative ways to capture and sustain student attention for better understanding of the instructional material. As Wiggins and McTighe (1998) said, teaching for understanding "has to be every teacher's purpose in teaching" (p. 112). Scientific conclusions have to be artfully interpreted and applied to particular educational situations, assuming that there is something to apply (Dewey, 1963). Based on this philosophical stance, the teacher-researcher meaningfully incorporated two concepts in science for easy understanding by the students.

Connecting to the real world. The best intellectual learning occurs in a context that illustrates its practical value (Shaker, 2001). Brodhagen, Weilbacher, and Beane (1998) proposed that if the curriculum is to support a genuine search for self and social meaning, then it ought to be drawn from concerns young people have about themselves and their world. Bearing this in mind, the teacher-researcher modified the instructional material of a fifth-grade science class on the topic of Photosynthesis and Respiration to connect students' learning to the world around them. The aim was to bring in environmental awareness and a sense of appreciation of the environmental processes that occur in nature. In accord with the words of Art Hobson (2000), it is necessary to "introduce scientific terms only when they are useful in describing or understanding a significant concept. And introduce the concept first, convince students that it is useful, and only then give it a name. It's the idea, not the name that is important" (p. 239).

Changing the title to make photosynthesis and respiration easily understandable. To begin, the author changed the title of the unit Photosynthesis and Respiration to Two Equations of Life. This was to attract the attention of the students and to emphasize the importance of what was being taught. When the title was presented to the class, there was complete silence and rapt attention as the students were curious to know how these equations were important in their lives. They read out the following equations written on the blackboard:

Two Equations of Life

1. <u>Photosynthesis</u>

$$\text{Water} + \text{Exhale from living organisms} \xrightarrow[\text{Green plants}]{\text{Sunlight}} \text{Food} + \text{Source of life}$$

2. <u>Respiration</u>

$$\text{Food} + \text{Source of life} \longrightarrow \text{Exhale from living organisms} + \text{Water} + \text{Energy of life}$$

Rather than use the chemical terminology carbon dioxide (CO_2) and oxygen (O_2), the teacher-researcher preferred to initially use the simple phrases *exhale from living organisms* for *carbon dioxide*, *source of life* for *oxygen*, and *food* for *sugar*. The purpose of adopting these simple alternatives was to use language familiar to the students that would also fully explain the meanings.

Explaining the first equation. To explain the first equation, one of the students was asked to volunteer to act as a tree. The author then made a comparison of the student's feet to that of roots of a plant, his legs and upper body to the body of the plant, his arms to the branches of the plant, and his hands and fingers to the leaves. Pointing to the feet, the teacher-researcher explained that the tree picks up water and minerals from the soil through the roots. The teacher-instructor then explained how the plants pick up carbon dioxide from the exhale of living organisms and the emissions from burning fossil fuels in human-built factories.

The green portions of the plant, in the presence of sunlight, transform the two substances on the left-hand-side of the equation to sugar, which we use as food. In this process, green plants also give out the source of life (oxygen) which is an utmost necessity for the sustenance of life on this planet. The students were asked to close their eyes for a while and imagine that they were trees. They were asked to think what will happen if someone tries to inflict injuries on them. Needless to say, the importance of saving plants for a safe planet was automatically imbibed by students. Thus, the students were guided to develop the right attitude towards environmental protection. Later, the teacher-researcher familiarized the students with the words *carbon dioxide* (for exhale from living organisms) and *oxygen* (for source of life). In this way, there was a gradual shift from known to unknown.

The second equation. The students were then asked how we get energy. The response was overwhelming as they answered in chorus that it is from the food we eat. The teacher-researcher then proceeded to say that plants are the important sources of our energy and that it is necessary for us to grow more of them. During food preparation, plants give out oxygen which is the source of life. We inhale this oxygen to destroy and convert the food that we eat and, in turn, release water and carbon dioxide. Water is given out as urine and sweat, while carbon dioxide is exhaled through our nose. The energy that is released at this time is used for all our life activities such as moving, jumping, thinking, and talking.

Conclusion. The teacher-researcher described the mechanisms underlying photosynthesis and respiration by arousing the curiosity of the students (using an attractive title), sustaining their interest throughout (relating to real life activities), and using simple language (appropriate to their level of understanding).

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Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

So Where is Your Homework?

By: Erica Brownstein, Capital University, Columbus, OH, USA ebrownst@capital.edu

I was checking homework. This was a regular routine in my high school chemistry class. I believed that homework was essential to helping students not only learn the subject at hand, but also to be successful in college. And then there was Brian. “Brian, where is your homework?” “I didn’t do my homework.” I mustered up my most matronly voice: “I’m concerned. I see that you haven’t turned in homework for awhile now.” “Mrs B, I’ve already failed your course.” I was stunned. “I don’t understand.” “Well, if you fail four of the six grading periods, you fail a course. So, I figured it doesn’t matter if I do homework. I like your class and I like chemistry. I don’t like doing homework anyway.”

I was in shock. How could Brian have failed my class? Sure, he didn’t do homework and yes, he performed poorly on tests. But, he was often the one in class who was helping other students do their homework. He would positively lead groups of students in activities or labs.

I knew immediately that I had failed Brian. It took a while to uncover exactly how I had failed him. I called his Mom and spoke to her. “We understand that he didn’t pass your class. Chemistry is a difficult subject. Brian has not done well in school, so we weren’t sure taking chemistry was a good idea anyway. We are happy with the class and feel that he was treated fairly. He talks about how much he has learned.”

It seemed no one was upset about Brian’s failure but me. I looked closely at his grades. The grading system for chemistry consisted of tests, quizzes, a lab notebook, and homework. It was at that moment I realized how I had failed Brian. I had not evaluated his learning through his areas of strength. Evaluations were focused on written evidence of understanding, something Brian was not particularly good at or inclined to do.

My entire approach to teaching changed. I sought out books and resources on alternative assessment. I kept close track of student grades and if a student was failing, I considered what I could do to address the student's strength areas. I started asking students explicitly: "How can we better meet your needs in this class?"

This experience has guided my career as a science educator both while in high schools and now at the college level. Creating an environment where students can demonstrate what they know and are able to do is central to my teaching. Brian is never far from my thoughts. My obligations as a teacher and facilitator of learning are clear to me now.

Science Poetry

Reading and/or listening to poems composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Water

Humans find water so much fun,
Splashing around, in the sun.
We swim about, for swimming lessons,
Divided up, in different sections.
Swimming levels: four, five and six,
Different swimming types, freestyles and frogkicks.

But water is not just for our leisure,
Though it gives us lots of pleasure.
Our body uses it, to stay alive,
So we need to drink it, to survive.
I don't know why our body needs it,
But we still do, and we need to feed it.

Enough of talking about what water does for us,
It also provides homes for thus:
Whales, dolphins, blowfish and sharks,
Swimming around like colourful darts.
A plethora of water covers the earth,
Sheltering animals, and quenching our thirst.

Luke Suter, 11 years
Australia

The Digestive System

You grab a piece of food
And chew and chew and chew
But little do you know
The process it goes through

First it goes in your mouth
With your saliva mixing it
The enzyme breaks it down
Make sure you don't spit!

Then it reaches the oesophagus
25 centimetres long
Food is pushed to the stomach
Where it should belong

Stomach muscles churn and grind
Helping it to break down
This takes a long time
No, your food won't drown!

Pancreatic juices help
To digest proteins and more
This then goes to the small intestine
And that is for sure

Then it arrives at the gall bladder
Where bile is stored
This is needed after meals
The journey is not finished--stay on board!

The small intestine is finally here
Where food gets digested even more
This is the main digestive organ
But there's one more thing to explore!

Finally the large intestine
In the rectum unwanted items are placed
Then they exit the body
And are seen as human waste.

Katrina Cruz, 14 years
Australia

Students' Alternative Conceptions

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Global Warming and Ozone Depletion

Which of the following statements is/are true?

a. Global warming is the result of more solar radiation entering the atmosphere through the ozone hole.
b. The greenhouse effect is a natural phenomenon.
c. Global warming causes skin cancer.
d. Carbon dioxide destroys the ozone layer.

Statement a. is the only correct one. Both students and the general public often confuse the greenhouse effect and ozone depletion. The greenhouse effect, in which naturally-occurring gases such as water vapour, carbon dioxide, and methane trap heat energy radiated by the Earth's surface and re-emit it back towards the Earth, is a natural phenomenon. Without this effect, this heat energy would escape into space and the surface temperature of the earth would be -18ºC instead of the 15ºC average that we enjoy. The enhanced greenhouse effect is caused by additional greenhouse gases, such as carbon dioxide produced by coal-burning power stations and the burning of fossil fuels, entering the atmosphere, producing what is commonly called global warming. In fact, global heat retention is a more accurate description, because the long-term melting of surface ice consumes heat energy with no increase in temperature.

The ozone layer filters ultraviolet radiation from the Sun, thus providing some cancer protection. Ozone depletion is caused by chemicals such as chlorofluorocarbons and halons being released into the atmosphere. Ozone-depleting chemicals are also greenhouse gases, as is ozone itself.

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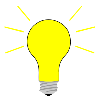

Ideas in Brief

Ideas from key articles in reviewed publications

Context-Based Science Courses

Being suspicious of the idea that any "magic bullet" might overcome the problem of designing science courses that attract students, Ogborn (2008) has doubts about the relatively-recent, common suggestion that all science courses should be designed around a set of engaging contexts. His concerns include the following:

- Because the chosen contexts need to address a set of ideas and explanations, and in some sequence, changing a context may not be easy since the ideas it contains need to fit with the broader framework.
- Interest in, and the importance of, a context may change with time (e.g., television sets are being replaced with LCD displays).
- Some contexts (e.g., the science of solid confectionery) might lose their charm for the teacher who is teaching the lessons for the third or fourth time.

At the same time, Ogborn (2008) acknowledges that there is a place for context-based learning (e.g., teaching basic DC circuits in the context of using modern electronic sensors in measurement). However, he also recognizes that teaching around conceptual issues (e.g., what is the nature of light?) can likewise be highly motivating and engaging for many students. So, given that human beings vary in what interests them, courses might best be designed so as to incorporate both contextual and conceptual topics.

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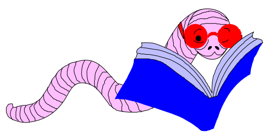

Research in Brief

Research findings from key articles in reviewed publications

Take a Text or a Sheet to a Physics Exam?

While taking a physics exam, students can be offered the opportunity to use a textbook (open text), a student-generated facts and formulae sheet (a "cheat sheet"), no book or notes (closed book/closed notes), or an instructor-prepared facts and formulae sheet, although opinion on the relative merits of these approaches varies. Hamed (2008) compared the performance of college students using a “clean text” (i.e., no notes or writing in it) with that of using a student-generated cheat sheet in the context of answering multiple-choice questions, requiring a combination of analytic qualitative reasoning and quantitative reasoning, on electricity, magnetism, and waves and optics.

Despite the majority of students preferring to have the textbook available, the use of the sheet, which was letter-sized (8.5- x 11-inch) and contained facts, formulae, and whatever else students thought might be useful, resulted in higher achievement. The sheet may promote more study and better organization of thoughts and concepts. Interestingly, most A students preferred using the sheet while most C and below students preferred the security of having the text, even though we do have evidence that they may not have read the text before the exam (Podolefsky & Finkelstein, 2006).

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School Size and Adoption of Technology

Many factors have been found to impact on teachers’ acceptance of, and resistance to, the use of technology. Wu, Hsu, and Hwang (2007) focused on the effect of school size, surveying 940 junior high school teachers of science and mathematics in Taiwan to conclude that small schools provide a better environment for designing and implementing instructional activities with technology. Teachers at small schools are more likely to have positive attitudes toward technology and more likely to use educational technology for classroom instruction.

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Wu, H-K., Hsu, Y-S., & Hwang, F-K. (2007). Factors affecting teachers’ adoption of technology in classrooms: Does school size matter? *International Journal of Science and Mathematics Education*, *6*, 63-85.

Effect of Answer Order on Multiple-Choice Questions

Tellinghuisen & Sulikowski (2008) analysed student performance on two versions of a multiple-choice exam, for a cohort of 1st-year general chemistry university students in the United States, differing in the order of both questions and answers. The evidence supports the notion that performance on a four-choice question can depend strongly on the order of the answers (and, to a lesser extent, overall performance on an exam can also depend on the question order). Students tended to exhibit a primacy effect, but with an A answer aversion. In other words, there was a tendency for better performance on questions where the correct answer appeared early rather than late.

In this case, the primacy effect appears to have averaged out across all questions in the exam. However, the implications are more important for other contexts, such as the construction of election ballot papers.

Reference

Tellinghuisen, J., & Sulikowski, M. M. (2008). Does the answer order matter on multiple-choice exams? *Journal of Chemical Education*, *85*, 572-575.

Effects of Context-Based and STS Approaches

Context-based and science-technology-society (STS) teaching approaches have been widely used in science education during the past 20 years. In the former, contexts and applications are used as the starting point for the development of ideas, in contrast with the traditional approach of ideas first, followed by applications, and the latter links science, technology, and society.

Based on 17 experimental studies, involving students aged 11 to 18 years from eight countries, that were identified by a systematic review of the literature, Bennett, Lubben, and Hogarth (2007) concluded that context-based/STS approaches improved the attitudes of both boys and girls to science, reduced the gender difference in such attitudes, and facilitated an understanding of scientific ideas comparable with conventional approaches.

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Gender-Related Aspects of Students' Science Questions in Online Free-Choice Environments

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The wealth of data regarding boys' and girls' interests in science shows that boys, in general, are more interested in science, especially in the fields of physics and technology, than girls. Girls, on the other hand, are more interested in biology than boys (Gardner, 1998; Sjøberg, 2000). Interest in, and attitudes towards science also change as a function of age. Students, especially girls, tend to lose interest in science as they grow older, mainly in the middle-school and high-school years (Reid & Skryabina, 2003).

This is important to science educators, because adolescents' decisions concerning the content and direction of their educational training and career choice are strongly influenced by the topic-related interests they develop during the preceding years (Krapp, 2000). Interest also affects what students are able to learn, with positive relationships having been reported between interest and a wide range of learning indicators (Pintrich & Schunk, 2002; Schiefele, 1998; Seiler, 2006).

Many of the explanations for girls' disinterest in science in general and physics in particular focus on the role of the educational system in creating this situation. Therefore we thought it might be useful to use evidence from free-choice science learning settings to study if this lack of interest is also expressed in non-school settings.

Research approach and methodology. Interest in science has been traditionally identified using written questionnaires (e.g., Dawson, 2000; Qualter, 1993; Sjøberg, 2000; Sjøberg & Schreiner, 2002; Stark & Gray, 1999) that rely on adult-centric views of what subjects should be meaningful to students. We assume that relying on children's spontaneous ideas and questions may be a better measure of their interests, and may enable progress towards incorporation of their views into the school curriculum, more than using their responses to an adult-written questionnaire. Responses to a questionnaire are externally regulated, while asking a question is a self-regulated action (Deci, Vallerand, Pelletier, & Ryan, 1991) and should therefore be a stronger measure of interest.

Students questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph, Symington, & Osborne, 1986; Brill & Yarden, 2003; Scardamalia & Bereiter, 1992). Despite the capacity of students' questions for enhancing learning, much of this potential still remains untapped (Chin & Osborne, 2008). It is hard to use children's questions for research in a classroom setting, since they are so rare and seldom give evidence of genuine intellectual curiosity (Dillon, 1988). Researchers attribute this situation to a classroom atmosphere in which revealing a misunderstanding may render the student vulnerable, open to embarrassment, censure, or ridicule (Pedrosa de Jesus, Teixeira-Dias, & Watts, 2003; Rop, 2003). However, students do pose science questions in free-choice science-learning environments. Therefore, we used children's self-generated science-related questions, submitted to Ask-A-Scientist websites and TV shows, as a tool to probe students' scientific interests.

The data source comprised over 90,000 science and technology questions collected from different web-based and TV-based sources. Multiple approaches were used to identify the sex of a question-asker. Hebrew is a gender-identifying language. As a result, some of those submitting questions automatically revealed their sex through the use of verb gender indicators. Children's given names provided a further indication of the sex of the questioner. For questions in English, gender identification was based on the asker's first name. In some cases, an initial classification was performed semi-automatically using *Japan Online Directory* (2006) (an English name gender finder), followed by manual classification using *Baby Name Guesser* (n.d.), which operates by analyzing popular usage on the Internet. In other cases, only manual identification was carried out.

Findings and conclusions. Internet-based Ask-A-Scientist sites demonstrated a surprising dominance of female contributions among K-12 students, where offline situations are commonly characterized by males' greater interest in science. This female enthusiasm was observed in different countries, and had no correlation to the level of equality in those countries (Baram-Tsabari, Sethi, Bry, & Yarden, in press). This may indicate that the internet as a free-choice science-learning environment plays a potentially empowering and democratic role which is especially relevant to populations that are deprived of equal opportunities in learning formal science.

However, girls' interest in submitting questions to scientists dropped all over the world as they grew older (Baram-Tsabari et al., in press), and the stereotypically-gendered science interests persist in this environment as well; that is, physics proves significantly less interesting to girls than to boys, while biology is of greater interest to girls than to boys. While boys develop an interest in physics with age, girls do not develop such an interest to the same degree (Baram-Tsabari & Yarden, 2008).

However, topics that appeal to both sexes and arouse spontaneous interest were also identified and include anatomy and physiology, neurobiology, sickness and medicine, and meteorology (Baram-Tsabari, Sethi, Bry, & Yarden, 2006; Baram-Tsabari & Yarden, 2005). Therefore, it seems possible to teach scientific concepts in the context of topics that are not profoundly preferred by boys. Using these topics as the context of science learning could prove beneficial in the process of developing learning materials that are more appealing to students and aligned with their scientific interests.

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Implementing Peer Instruction in Pre-University Courses: Clickers in Classrooms?

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Peer Instruction (PI) is a student-centered, instructional approach developed by Harvard physicist Eric Mazur (Crouch & Mazur, 2002; Mazur, 1997). In PI, students follow a brief lecture (approximately 10 minutes, and within the limits of average attention span) that ends with a ConcepTest, which is a multiple choice conceptual question that usually incorporates misconceptions as possible choices. Students pick their choice of answer to the ConcepTest either by raising a flashcard that displays one of the letters A-E in large print or by using a clicker that sends their choice to the instructor's computer.

ConcepTests provide teachers with real-time feedback of the proportion of students having the correct answer. More importantly, ConcepTests show the distribution of misconceptions. Assessing comprehension in real-time allows teachers to decide how to proceed; that is, to move on with another concept or to spend more time on the concept at hand. Specifically, if the concept is poorly understood (< 30% of correct answers on the ConcepTest), the teacher revisits the concept before resubmitting the ConcepTest to the group. If the correct response rate is very high (>80%), the teacher addresses the misconceptions that the remaining 20% of the class hold and proceeds to the next concept. Most frequently, the correct response rate is neither very high nor very low. When moderate response rates (30%-80%) are obtained, students are asked to turn to their neighbours and try to convince them of their choice. This leads to a 2-3 minute discussion between students; the Peer Intruction per se.

This discussion helps students formulate their thoughts and better represent the concept. Furthermore, student discussions sidestep the authoritative nature that discussions with teachers can have. Indeed, students may take teachers' explanations as "fact" and not pursue a line of reasoning with the same degree of elaboration as might be the case with a peer. Students also discuss from perspectives that are often foreign to the expert-teacher, making students better equipped than teachers at understanding their peers' misconceptions. Thus, peer discussions may facilitate conceptual change. After discussion, students revote on the ConcepTest. The teacher then reveals the correct response and explains why the remaining misconceptions are wrong.

This report is an adaptation and summary of Lasry (2008a) and Lasry (2008b) and focuses on the following three questions:

1) Can PI be implemented effectively in a pre-university context?
2) Is PI with clickers more effective than with flashcards?
3) How do students respond to PI?

The research comprised three groups of mainly 17-year-old students; one PI group using clickers, one PI group using flashcards, and one traditional didactic instruction group. To compare the effectiveness of PI with respect to traditional teaching, both PI groups were pooled and compared to the traditional group. To determine the added value of clickers, the PI group with clickers was compared to the PI group with flashcards. The groups were compared as to how well they performed in a traditional final exam. However, students may know how to solve numerous problems without understanding the basic underlying concepts (Kim & Pak, 2002). To assess their conceptual understanding, students were also given the Force Concept Inventory (Hestenes, Wells, & Swackhammer, 1992) before and after the course. Finally, a survey was given at the end of the course to determine students' appreciation of the approach.

Although no significant difference in conceptual understanding was present between groups before instruction, the PI groups learned significantly more concepts than the traditional instruction group. Thus, PI enabled more conceptual learning than traditional instruction in pre-university settings as it had at Harvard (Mazur, 1997). This result is also consistent with Hake's (1998) findings on the difference between traditional instruction and active engagement methods (with a range of methods including PI).

Some teachers voice concerns about methods such as PI. Specifically, the greater amount of time spent on concepts in PI necessarily takes time away from in-class problem-solving. Since problem-solving skills are very important in science, some teachers feel that the added conceptual gains come at the cost of losses in problem-solving skills. However, the study results show that PI students obtained slightly better results on the traditional problem-solving exam. Therefore, although more time is spent on conceptual learning and less time on algorithmic problem-solving, students in PI groups do not have lesser problem-solving skills.

At the beginning of the course, the clicker and flashcard groups did not differ in conceptual understanding. At the end of the course, while both the clicker and flashcard groups had gained more conceptual knowledge than the traditional group, the clicker group did not differ from the flashcard group in either conceptual learning or problem-solving ability. Thus, the effectiveness of PI cannot be attributed solely to the clicker technology. PI is an effective pedagogy that is independent of the use of technology such as clickers. Finally, when surveyed at the end of the semester, both clicker and flashcard students responded positively to PI by acknowledging its advantages as an instructional approach and preferring it greatly to traditional instruction.

In conclusion, Peer Instruction is effective even in pre-university settings. The approach is simple to implement and well-received by students. Its strong emphasis on concepts does not hamper students' ability to solve traditional algorithmic problems. Indeed, less time is spent on algorithmic problem-solving, yet the conceptual background students develop allows them to be more effective at problem-solving. Interestingly, the use of clickers instead of flashcards did not provide any additional conceptual learning benefit to students. PI is an elaborate pedagogical approach that places a strong focus on basic concepts, requires students to commit to a conception, and provides a setting for peer discussion to sort out accepted concepts from misconceptions. Clearly, the pedagogy is much more than the technology by itself. That is not to say, though, that clickers should be abandoned. Although flashcards and clickers were found to be equally effective in promoting learning, clickers do provide advantages for teachers. First, teachers can survey students anonymously, automatically, and accurately (no need to count flashcards). Second, the responses of students obtained using clickers can be readily archived, allowing teachers to see which questions work better than others and to use this information in shaping the content of future courses. Some readers may be interested in PI methodology and willing to reshape their instruction to provide a greater focus on basic concepts. Yet, the price of clickers and related hardware may be prohibitive. In this instance, PI should be implemented with flashcards as it is the PI pedagogy that is effective and not the method used by students to report their answers.

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The Importance of Pupils' Interests and Out-of-School Experiences in Planning Biology Lessons

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Abstract

How to make learning more interesting is a basic challenge for school education. In this Finnish study, the international ROSE questionnaire was used to survey, during spring of 2003, the relationship between interest in biology and out-of-school experiences for 3626 ninth-grade pupils. Interest and experience factors were extracted by using the explorative factor analysis. Out-of-school, nature-related experiences, including watching nature programs on television, reading on nature from books or magazines, or having out-of-doors, nature-related hobbies were the most important factors correlating with interest in various contexts of human biology/health education like health and illness, personal appearance and fitness, human body in extreme conditions and in general biology like zoology, applied biology and genetics, and evolution. Out-of-school experiences in science and technology-related activities, such as using science kits and constructing models, had surprisingly the highest correlation with an interest in basic processes in biology, such as conceptually more abstract phenomena in ecology or cell biology. Design and technology-related experiences, such as using large tools, or experiences in using computers and mobile phones, were the least important factors to correlate with the studied interest contexts. More boys than girls were interested in basic processes of biology, while more girls than boys found human context interesting. When planning biology lessons and field work, it is important to connect pupils' out-of-school, nature-related hobbies and experiences to biology education, because they may represent longer-lasting personal interests. (Most of this paper is a summary of Uitto, Juuti, Lavonen, & Meisalo, 2006)

Interest is Essential for Efficient Learning

How to enhance pupils' interest and motivation to study science has remained a perpetual challenge for school science education. Krapp (2002) and Schiefele (1991) have stated that interest is a central precondition for intrinsic motivation and, according to Sansone, Wiebe, and Morgan (1999), interest is essential to maintain motivation over time. Thus, a critical question for school science education is how interest can be developed and maintained.

Many studies have shown that interest-triggered learning activity leads to a higher degree of deep-level learning (Krapp, 2002). Most researchers differentiate between personal and situational interests (Krapp, Hidi, & Renninger, 1992). Personal interest is understood to develop gradually and affect one's knowledge and values over time, while situational interest appears suddenly as a response to something in the environment and is more emotional in nature (Hidi, 1990). Situational interest is thought to have only short-term impact, whereas personal interest is believed to be more stable. The general view of school education is that pupils' knowledge of a school subject is acquired in the classroom within varying educational settings organized by the teachers. Moreover, Braund and Reiss (2006) suggest that "school science teaching needs to be complemented by out-of-school science learning that draws on the actual world (e.g., through fieldtrips), the presented world (e.g., in science centres, botanic gardens, zoos, and science museums), and the virtual worlds that are increasingly available through information technologies" (p. 1373). However, very little importance has been attached to children's out-of-school experiences. Informal learning may occur at home in everyday situations like with friends, watching TV, reading books or magazines, and in various hobbies, as well as in institutions like museums and zoos, and out-of-school activities and experiences may also enhance children's interest in school subjects.

ROSE Project Surveys Pupils' Interest in Science

To clarify the role of affective factors of importance to the learning of science and technology by ninth-grade pupils, an international comparative research project, The Relevance of Science Education (ROSE), was organized (Schreiner & Sjøberg, 2004). The Finnish ROSE project was started in 2003 (Lavonen, Juuti, Meisalo, Uitto, & Byman, 2005). Pupils' interest in biology and their out-of-school experiences were one part of the study (Uitto, Juuti, Lavonen & Meisalo, 2006). The ROSE questionnaire contains 108 statements for pupils' interests in science education and 61 statements on their out-of-school activities. Eight questions, based on the national curriculum, concerning interest in basic biological processes were also included. For each statement, the pupils were asked to indicate their response by ticking the appropriate box below the topics: "What I want to learn about? How interested are you in learning about the following?" and "My out-of-school experiences. How often have you done this outside school?" The interests were studied using the scale *Not Interested* to *Interested* and out-of-school activities with the four-point Likert-scale from *Never* to *Often*. The responses of 3626 pupils (49% girls) with median age 15 years were reduced to eight interest-context factors and seven out-of-school experience factors with an explorative factor analysis. Each factor was named according to the loaded items, emphasizing the contents of the factor items (see Tables 1 and 2). A more detailed analysis of the study is described by Uitto, Juuti, Lavonen, & Meisalo (2006).

The results of the study indicate that girls were more interested in biology, especially in the context of human biology and health education. Only in the context named *Basic Processes in Biology* did more boys than girls find biological phenomena, such as the functioning of genes, cells, or food webs, interesting. Gender difference was large, for instance, in the interest contexts named *Personal Appearance and Fitness* ($M_{girls}>M_{boys}$) and in the out-of-school experiences of *Science and Technology* ($M_{boys}>M_{girls}$) and *Home Economy'* ($M_{girls}>M_{boys}$). This is in accord with the study of Lavonen, Byman, Juuti, Meisalo, & Uitto (2005) that found from the same ROSE data that, in physics contexts, the most interesting things for girls were connected with human being and the less interesting with artefacts and technological processes.

The out-of-school *Nature* experience factor, that includes watching nature programs on TV, reading on nature from books or magazines, and having out-of-doors nature-related hobbies, was the most important experience factor to correlate with the interest-context factors (Uitto, Juuti, Lavonen, & Meisalo, 2006). Even if girls had *Nature*-related activities outside school more often than boys, the correlations between the *Nature* experience factor and most of the interest-context factors seemed to be more evident in boys (Tables 1 and 2). Out-of-school experiences in *Science and Technology*, including science kits and constructing models, had surprisingly the highest correlation with the interest context of *Basic Processes in Biology*, such as interest in phenomena requiring reasoning in ecology or cell biology. However, boys' and girls' *Science and*

Technology-related experiences correlated clearly also with the interest context of *Applied Biology*, including interest in more concrete and practical issues in biology, such as interest in plants and animals and how to improve the harvest in gardens and farms. Out-of-school experiences of *Farm Animals* had understandably a relatively high correlation with the interest context of *Applied Biology*. *Design and Technology*-related experiences, such as using tools for gardening or handicraft, or experience in *Computer* and *Mobile Phone*, were the least important factors to correlate with the studied interest contexts. When planning and carrying out classroom and out-of-school lessons in biology, it would be beneficial to take into consideration pupils' out-of-school experiences and interests.

Table 1
Correlation Coefficients (Spearman's Rho) Between Girls' Interest Context Factors and Out-of-School Experience Factors

Experience factors	Interest factors							
	Basic processes in biology	Common health and illness	Personal appearance and fitness	Applied biology	Zoology	Human body in extreme conditions	Sex and reproduction	Genetics and evolution
Science and technology	**0.37****	NS	NS	**0.26****	0.13**	0.16**	0.06*	0.09**
Nature	0.16**	0.14**	0.10**	**0.38****	**0.36****	**0.24****	0.10**	**0.27****
Computer	NS	0.07**	0.05*	NS	0.11**	0.11**	NS	0.07**
Farm animals	0.18**	NS	0.08**	**0.35****	0.16**	0.10**	0.12**	NS
Design and technology	0.11**	NS	NS	0.16**	0.11**	0.12**	0.09**	NS
Mobile phone	-0.18**	0.11**	0.08**	NS	0.12**	0.08**	0.09**	NS
Home economy	NS	0.16**	0.15**	0.20**	0.14**	0.13**	0.13**	0.17**

Note. Coefficients ≥ 0.24 are shown in bold. NS = not significant. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

Experiences and Interest in Learning Biology

The findings have several implications. First, when planning and implementing lessons in biology or health education, it would be important to remember that pupils' out-of-school experiences, and especially *Nature* experiences, may enhance their interest to study biology. Thus, to increase pupils' motivation and skills to learn biology, it would be profitable to connect pupils' out-of-school nature experiences to school education. If a pupil has, for instance, many *Nature* or *Science and Technology*-related experiences and hobbies, these may also represent his or her longer-lasting personal interest and engagement to learn more about living nature in school. These pupils could perhaps motivate their schoolmates to learn biology or take an interest in nature-related hobbies. Schools could, for example, organize nature clubs where experienced pupils tutor younger pupils during a bird watching trip, visit to a zoo, and the like.

Second, it would be important to regularly organize well-planned, outdoor biology education because fieldwork, with its small-scale studies and observations, offers an experiential and contextual way to learn about, for instance, ecosystems. Learning at zoos, botanical gardens, or science parks may enhance pupils' interest in learning more about biology. In general, pupils are usually able to remember out-of-school learning experiences better than the more conventional classroom lessons. Actual and situational interest may be the first step in the development of more consistent personal interest in biology, or science in general. Third, boys and girls may be interested in different content and contexts of biology, with girls being, on average, more interested in human-related contexts. At least some technologically-oriented boys could become more interested in human biology or health education if, during the lesson, they are allowed to use appropriate instruments to measure things like blood pressure, lung volume, and heart pulse or to count steps.

Table 2
Correlation Coefficients (Spearman's Rho) Between Boys' Interest Context Factors and Out-of-School Experience Factors

Experience factors	Interest factors							
	Basic processes in biology	Common health and illness	Personal appearance and fitness	Applied biology	Zoology	Human body in extreme conditions	Sex and reproduction	Genetics and evolution
Science and technology	**0.36****	0.07**	0.21**	**0.33****	0.16**	0.16**	0.13**	0.17**
Nature	**0.31****	**0.27****	**0.26****	**0.39****	**0.39****	**0.33****	0.16**	**0.30****
Computer	0.05*	0.10**	NS	-0.09**	0.12**	0.21**	0.07**	0.07**
Farm animals	0.23**	0.06**	**0.28****	**0.44****	0.10**	NS	0.11**	0.10**
Design and technology	0.12**	0.07**	NS	0.10**	0.13**	0.17**	0.14**	NS
Mobile phone	-0.07**	0.09**	-0.08**	-0.13**	0.11**	0.16**	0.08**	NS
Home economy	0.15**	0.19**	0.19**	0.22**	0.21**	0.23**	0.16**	0.18**

Note. Coefficients ≥ 0.24 are shown in bold. NS = not significant. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

Curricular Goals and Out-of-School Biology Education

Out-of-school education needs careful planning, along with prior and subsequent work at school and consideration of the curricular goals. Many of the interest contexts appearing in the study belong to the Finnish core curriculum for comprehensive biology education, such as species kingdom, basics of ecology, human biology, evolution, genetics, and applied biology, as well as health and environmental education. For instance, pupils learn the characteristics of Finnish ecosystems and conduct a small-scale study of one ecosystem during the seventh and ninth grades. Thus, skills to plan, perform, and evaluate out-of-school education are important for the biology teacher.

As a new, temporary, written objective, making a herbarium is also mentioned in the Finnish core curriculum. In the context of outdoor ecology education, the use of information technology may have many new possibilities, such as saving authentic information on plants and biotopes using digital cameras or portable phones when studying ecosystems. The whole field excursion can be recorded as a later reminder of what kind of observations and small experiments were made. Thus, the use of information technology in field education may surprisingly also motivate keen computer users to find a way to observe nature out-of-doors.

From School to Real Life

Motivating nature experiences would be important especially for pupils who miss such experiences in their free time. Out-of-school excursions may encourage pupils to engage in various nature activities and hobbies in their free time. Moreover, pupils' positive nature experiences and values are suggested to relate with positive attitudes towards responsible environmental behavior (Uitto, Juuti, Lavonen, & Meisalo, 2004). Some pupils were interested in applied biology. Visits to farmhouses, gardens, or food industry facilities may therefore be interesting in helping to learn where and why biological knowledge and skills are needed in real life, such as in various professions. With human biology and health education being interesting topics for pupils, health rehabilitation institutions and first aid centers may be good places to visit and learn to appreciate the work of people within the health care sector. At one's best, classroom education, out-of-school education, and informal learning complement each other.

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Readers' Forum

Inquiry (Continued)

The discussion regarding the meaning and use of the term inquiry is intriguing. I would like to react to and enlarge on some of Peter Eastwell's questions and concerns. Most personal curiosities, if investigated, are guided by past experiences, interpretations, and beliefs of the person who is curious. Hence Peter is correct insisting that there is really no unguided inquiry. To me the important thing is that students be encouraged by teachers and others to pose their own questions--those related to their communities, schools, and families. In Science classes they should be encouraged to identify questions for projects that are: 1) personally relevant and interesting; 2) related to current situations, and 3) locally based. As long as one assumes that such questions can be answered and that possible answers can be evaluated with evidence, it can be argued that this is actually one way of "doing science." Too often dealing with curiosities stop with personal guesses and/or interpretations unrelated to science (i.e., art, literature, and religion).

Eastwell has used the terms "guidance and direction provided," apparently thinking of teachers as providers. It seems to me that this limits the science to curricula and textbook summaries of what we think we know and puts the teacher in the roll of controller of instruction as well as director and initiator of ideas on decisions about what all students should know. These concerns are also noted as Eastwell worries about such questions in terms of fraction of time that should be given to open inquiry in courses. I would be happy if every K-16 Science course required one personal and/or one group project per year where students need to search out information needed to resolve a problem they have identified.

I continue to be concerned that too many students graduate from high school (maybe even college) without ever experiencing one complete experience with science, including using personal curiosities to pose a question about the objects and events encountered, attempting to answer the question(s), collecting evidence for the validity of the explanation(s), and checking with others (experts) concerning the explanations thought to be valid. Perhaps some of the debate about inquiry is caused by lack of agreement concerning what science is and how we choose to define science operationally.

Perhaps an example of open inquiry in Iowa would clarify my position. A chemistry teacher in Western Iowa was asked if he would organize and teach a "special" chemistry course for 15 female students who aspired to be hairdressers. This would be the course to fill his full teaching schedule instead of a teaching section of ninth-grade algebra. After some thought, he jumped at the chance. On the opening of classes in the fall, the teacher asked the students if they could conceive why the school counselor felt that a chemistry course might be useful, indicating that they would not follow a specific curriculum or use a textbook but that he wanted their experience to be meaningful and helpful. He asked the students for ideas of what topics might be studied. After a few days, ozone was mentioned as a problem area. The teacher was surprised to hear the term and the reason it was mentioned, but decided to use the student suggestion, thinking it might take a day or two.

To his surprise, the students never got off ozone that year. He reported that he never expected the student interest and their questions. For example: What does O_3 mean? What is a molecule? What is a solution? What is pH? What are elements? Compounds? The students saw a problem and wanted to help. They became experts! Later, they went to third-grade classrooms to discuss the problem, went to service clubs, and got the town mayor to declare ozone-depletion day in the city! The teacher indicated that the textbooks and other references were found helpful. But much more important was being in touch firsthand with experts.

One interesting comment from the students in several sections of the regular chemistry course was: "Why do those girls get to do all the important and fun things and we are stuck with the next chapter in a textbook and doing cookbook laboratories?" This experience led the teacher to teach the college preparatory courses in different ways.

Another hurried example was a high school where there were a dozen potential school drop-outs. A science teacher was charged with planning a meaningful course designed to keep the students in school rather than on the streets. They were interested in sports--football, expensive tennis shoes--and began discussing relative costs. They got into organic chemistry, polymers, plastics, and differences in sport shoes (the ones “rich kids” could afford). Because of their past poor behavior, they were initially denied use of the school library. The students got more and more involved with questions and activities that interested them. They even became better “school citizens”!

Too often teachers try new open approaches in problem areas, while maintaining the college preparatory functions that chemistry, physics, and advanced biology courses emphasize in high schools. The typical curriculum with discipline focuses characterizes the college science courses completed by most high school teachers. Since most high school teachers have rarely had a firsthand experience with science inquiry, many hesitate to change their teaching approaches.

It is planned that the November, 2008 issue of the NSTA *The Science Teacher* will emphasize examples of teaching science via projects designed for solving problems. NSTA is also publishing a sixth monograph as part of its Exemplary Science Program (ESP) dealing with inquiry. All chapters report on using situations that are offered as samples of an inquiry focus in K-12 classrooms, informal education arenas, and teacher preparation and professional development programs.

Eastwell asks for evidence that open inquiry is desirable and then calls unguided (open) inquiry “poor pedagogy.” If it is, why is there so much research indicating the advantages of it? When courses or units are approached as open inquiry, the following things happen:

- More positive attitudes develop for more students concerning science study, science careers, and science teachers;
- Students become more creative persons in terms of defining and refining their own questions and proposing possible answers;
- Students with open inquiry experiences are able to use the skills and concepts that characterize science courses in new contexts;
- Students who perform as open inquirers usually want more of it.

These all happen in varying degrees depending upon whether it is a 5-day trial, a 3-week unit, or a departure from the course guide for a semester or a whole year.

Researchers stress that the open inquiry approach is especially powerful in engaging low-ability and problem students in the learning process. Many assume that more learning results when it seems like play or comes from free choices. Often teachers get more comfortable not being the “sage on the stage” and see the advantages of student input, ideas, and problem identification/resolutions for mind engagement and success.

When used with high-ability students, some research illustrates that later instruction in college courses is criticized. In other words, there are now many college science faculty members willing to try problem resolutions and more student-centered approaches even in large lectures. Many institutions with model teacher education programs are assisting college teachers to do something more than sharing what they know with students, thinking the best students seem to learn what they are told or what cookbook labs illustrate.

Sometimes high-ability students who experience science as traditionally offered in high schools are negative with respect to inquiry foci because of their great success with being told what to do and following directions correctly. They do not like changes from the traditional teacher-directed classrooms in which they excelled; never questioning that their real learning was in question and perhaps alien to science itself. It seems to me that good teachers should always be a bit dubious about real learning and expect students to show their "knowing" by use of the information and/or skills in new situations.

Peter Eastwell has spent much time defining scientific inquiry, inquiry activities, and inquiry levels. Certainly these ideas and terms are useful as we all seek for more success with student learning in Science. It is important that we agree on definitions and that we see a use for them in our teaching and our efforts to improve. As indicated earlier, I prefer a more generic use of the term--not putting science and scientists on pedestals.

I like Eastwell's idea that open inquiry may be more important for elementary and/or middle schools. I agree; but my position is that most elementary and middle school teachers are very willing to admit that they do not know basic science. It is easier to convince them to try and to work with students without the problem of knowing too much--too much for students to learn--and deal with things they do not know with their own students. Perhaps the best model for an inquiry teacher is not sharing the things he/she knows but helping students advance their own unknowns by searching out ideas from others; students, parents, community leaders, professional scientists, and engineers. It may even be useful if the searches result in opposing views/ideas. The inherent student interest makes all of this easier to accomplish.

Modern science demands collaboration, where many views and ideas are shared. Why not so in science classes? It may be desirable if there are multiple differences in problem identification and proposals for their resolution. Too often students are denied experiences with the essential features of inquiry. In a sense, we are all guided by experts we seek out, written materials, and other people (including students) with whom we are in contact. Too often we as teachers feel content that we know what students need and will be able to use. Few doubt their wisdom. One Iowa biology teacher took great pride in former students returning to her classroom with praise, indicating that they were still using her notes taken in 10th-grade instead of those from the college instructor in whose course they were now enrolled. This judgment and compliment caused the teacher to continue giving students fine lectures, chalkboard notes, and promises that all the information was important and would be useful.

How could real inquiry by individual and/or groups of students be poor pedagogy??

Robert E. Yager, University of Iowa, IA, USA

While reading Robert Yager's foregoing contribution, my initial reaction was to ask why what I had been trying to communicate was being so misrepresented. After subsequent pondering, communications with Robert, and further reading, I have concluded that the reason for this, and for why Yager and I appear to be "talking past one another" rather than with one another, is that we still have differing views of what it means for students to be engaged in inquiry. So, given that what I have written previously appears to have been insufficient, I now welcome the opportunity to elaborate and, hopefully, clarify.

Definition of inquiry. I have previously distinguished between scientific and non-scientific inquiry (i.e., types of inquiry), and also between scientific inquiry and inquiry Science (the learning/teaching model). Further, in the context of the latter, I have used the definition of an inquiry activity as being one that requires students to answer a question by analysing information themselves. However, I now see the need to be more specific and note, in particular, that the information referred to here needs to be raw, empirical data. In short, then, an inquiry activity is one that requires students to answer a scientific question by analysing raw, empirical data themselves.

Let us consider the implications of this concept, as reflected in the work of others such as Dobson (2008), Farrell, Moog, and Spencer (1999), Leege (2008), Lunsford and Slattery (2006), and Wilhelm, Smith, Walters, Sherrod, & Mulholland (2008), for classroom practice. I have also mentioned previously that the data students analyse in an inquiry activity may be supplied by the teacher, collected by students, or a combination of these. As a good example of the former, consider how time-consuming, costly, and finicky it can be to have groups of students set up and use Millikan's apparatus to determine the fundamental charge, *e*. In any case, the focus in this exercise is on the data analysis rather than on gaining anything special from the process of setting up the apparatus. So, in accord with the suggestion of Pearson (2005), it might be preferable to provide students with some of Millikan's original raw data (e.g., different groups could be assigned data for different size drops), a description of the apparatus (a video or computer simulation showing it in action would be even better), and the relevant equations and invite them to use Microsoft Excel to analyse the data to determine the fundamental charge, *e*.

However, it is far more common for an inquiry activity to require students to collect data themselves (just like scientists need to do), and an excellent example of such an activity is an investigation students might perform to answer the question: "Does eating spicy food cause your core body temperature to rise?" During such an activity, the work of students also reflects the core work of scientists. The research, or investigatory, approaches of scientists may be categorized as experimental (traditional manipulative investigations comprising the control of variables and the assessment of cause and effect relationships), descriptive (correlational and/or observational studies, void of direct manipulative features and including modeling systems that use computer simulations developed from collected data), experimental/descriptive combination, or theoretical (comprising mathematical computations) (Schwartz & Lederman, 2008). While the latter is not really applicable to the school context, the scientific inquiry of scientists focuses largely on understanding the causal mechanisms that underlie natural phenomena (Russ, Scherr, Hammer, & Mikeska, 2008).

Now, here comes a key point that I think will illuminate a major difference I seem to have with Yager about the concept of an inquiry activity in science education. Consider the following questions: "How does electricity pass through a wire?" and "Did the cavemen have cats? Can you think of an investigation that students might perform to answer either question? No. These questions are not investigable in the school context. However, they might be readily answered by performing a library/literature search. Here, though, the information that students will be retrieving is not raw, empirical data for analysis (as is required in an investigation) but rather the conclusions of others (based on analyses that have already been completed) and, as Bell, Smetana, & Binns (2005) make clear, the retrieval of such information does not constitute inquiry. This is also in accord with the work of scientists, who do not typically investigate by simply synthesizing the conclusions of others. For this reason, then, I suspect that the ozone and sport projects Yager mentions also do not constitute inquiry.

At the same time, though, what are often called library research projects, that require students to find and process information other than raw, empirical data, can certainly make a valuable contribution to a curriculum, even though they do not constitute inquiry. In fact, a question might not even be involved. For example, Tribe and Cooper (2008) report on how a literature research project, which involved students collaborating in groups as they researched topics including The Effect Acid Rain has on Urban Environments and The Fermentation of Beer to produce a poster session, was successfully used to introduce students to peer-reviewed literature. Such projects, which include WebQuests, can also be useful for learning about socioscientific issues/problems, and controversial issues in particular, as in the case of trying to answer the question: "What is the best solution to a Foot and Mouth disease outbreak in this country? However, the treatment of socioscientific issues also requires a consideration of factors that are outside the realm of the nature of science; social, political, or economic concerns, value judgments based on beliefs, cultural differences, moral considerations, etc., personal opinion, and the like. By incorporating non-scientific considerations (e.g., personal opinions that are not based on empirical evidence and that cannot be tested), such activities cannot constitute inquiry (although the scientific components of them certainly could) and other strategies are available for dealing with such issues in the science classroom (e.g., see Oulton, Dillon, & Grace, 2004). Consider, then, the work reported by Yager, Kaya, & Dogan (2007) in which groups of students identified and aimed to resolve science and technology problems that included AIDS and Chemical War Gases and Their Characteristics using library and on-line searching, campus-based symposia, and communication with experts and then presented poster sessions. While the article does use the terms *inquiry* and *data*, I'm inclined to think that *project* and *information* (to describe the photographs, interviews, and "hundreds of pages of information"), respectively, might be more appropriate.

I should emphasise, though, that library searches are certainly not incompatible with inquiry learning. Consider, for example, the question: "What local climate changes, if any, are associated with El Niño?" A non-inquiry way to answer this question would be for students to retrieve the required information from the library and summarise it. However, an inquiry approach might see students using a library/on-line search to find the monthly temperature (and rainfall, etc.) data for their location for the most recent El Niño year and comparing it with the monthly averages for the past 50 years (Bell et al., 2005). Also, just as scientists use the results of literature reviews, information that is not raw, empirical data that comes from sources like library reviews can contribute to the report of an inquiry activity by providing background to the activity and/or being linked to the results of the inquiry in the conclusion section of the report.

So, this will hopefully make clearer why I am suggesting that Yager's more general ("generic," as he has called it) use of the term inquiry to mean "questioning in order to get information" is insufficient. In summary, inquiry (in the context of the inquiry Science model for teaching/learning) must see students answering scientific questions (not socioscientific questions, and obviously also not non-scientific questions) by analysing raw, empirical data (in contrast to evaluating and synthesizing the conclusions of others). To me, attempting to apply what the National Science Education Standards (National Academy of Sciences, 1995) has to say about inquiry to these other contexts does not make sense. As an aside, and a note of caution, though, we do appear to have some way to go in our understanding of how such projects, in the broader context, might be best implemented because, as Tai, Sadler, and Loehr (2006) found, "students who reported being assigned greater numbers of independent projects [in high school chemistry] typically earned lower grades in college chemistry" (p. 125). This clarification will hopefully also assist communication between science educators, because it is difficult for people to discuss an issue by using a term like inquiry without sharing the same definition of the term.

Allow me to conclude the treatment of this issue by sharing an example of how the lack of use of a common definition of inquiry might lead to much confusion. Imagine a science education research manuscript titled “An Inquiry into Teachers’ Inquiry of Inquiry Learning.” Confused? Well, if you’re not confused by the use of the term inquiry in the title, you probably would be confused by its use as you read the manuscript proper. Here we have the situation of teachers who have investigated aspects of inquiry learning in the classroom and an academic who has studied the processes undertaken by those teachers. Now, assuming that the work of both the academic and the teachers included obtaining data in the affective domain, for example, none of them have done either science (because the personal opinions of people do not constitute scientific data) or inquiry in the spirit of the Inquiry Science model for teaching/learning. Rather, they have conducted social science research, and a preferable title might be “A Study of Teachers’ Investigations Into Aspects of Inquiry Learning,” even though the term *investigations* is not being used in the scientific sense.

How much inquiry? The motivation for me asking what fraction of a course might best be Level 4 (open) inquiry (i.e., students designing methodologies to answer their own questions) was two-fold. First, I was asking Robert Yager to be more specific as to how much open inquiry he was recommending, because his descriptions of “open inquiry is what we should be aiming at” and “one activity per term, or whatever, as a start” (R. Yager, personal communication, May, 2008) were not sharing a clear vision. In particular, I was very keen to be critical if it turned out that he was advocating that an entire typical science course might be based on students’ questions. I’m content with his suggestion of one or two open inquiries per year.

This is also in accord with what others have been saying about inquiry in general (i.e., not Level 4 inquiry in particular). For example, “inquiry-based practices should be used as often as is practical. If students perform even a few inquiry-based labs each year throughout their middle school and high school careers, by graduation they will be more self-confident, critical-thinking people who are unafraid of ‘doing science’” (Deters, 2005, p. 1180). The phrase “as often as is practical” is important. For example, unlike in general chemistry, Level 3 inquiry (i.e., students designing their own procedures, whether in part or completely) is problematic in organic chemistry (Horowitz, 2007; Mohrig, 2004). Here, lower-level “cookbook” activities appear to have a valuable role (Ault, 2002), provided the recipes are not so dumbed-down as to require no thinking on the part of students (e.g., some information is left for them to figure out for themselves) (Horowitz, 2008).

In the event that there are readers keen on the idea of basing typical science courses on students’ questions completely, and even perhaps on project work aimed at answering these questions, allow me to share the following thoughts:

- There is no guarantee that students themselves will identify all the key concepts in a field of study that a graduate of a particular course might reasonably expect to have been exposed to.
- "It is clear that the biology curriculum cannot rely solely on students' interests" (p. 537) because, for example, they rarely asked questions about current topics such as biotechnology” (Baram-Tsabari & Yarden, 2007).
- Baram-Tsabari and Yarden (2007) wonder if free-choice learning might lose its appeal once it became compulsory, at the same time acknowledging that taking students’ interests into account is important. Again, as is typical in the field of education, an appropriate balance appears to be the key.
- “We suggest that a ‘some research curriculum’ [this includes projects] is good, but that an “all research curriculum” is both unnecessary and inefficient” (Brooks, Schraw, & Crippen, 2005, p. 643).

My second motivation for asking what fraction of a course might best be Level 4 (open) inquiry was linked with the idea that the amount of open inquiry might vary with year level in school, and to particularly test my suggestion that Level 4 inquiry (involving students using hands-on activities to collect data to answer their own questions) might not be a priority after, say, the compulsory years of education because the outcomes might not warrant the price to be paid in terms of the demands on budgets for somewhat specialised equipment and staff time. My suggestion would be weakened if there were examples of Level 4 inquiry being used in science courses throughout the tertiary (university) sector, so I have been most vigilant in trying to identify such in my reading. However, I am yet to find a single one, with the closest I have been able to find involving Level 3 inquiry only (Apedoe, Walker, & Reeves, 2006; Lord, Shelly, & Zimmerman, 2007). In fact, in the paper of Apedoe et al., whose work in implementing inquiry in geological science I regard to be exemplary, we find open inquiry mentioned early as a desirable aim but a later admission that the best they could do is Level 3 inquiry, with students also needing to be provided with a multitude of data from which to formulate their explanations. As Brooks et al. (2005) say, and in accord with the reasoning of Cheung (2008), inquiry is a difficult business and, to make inquiry work in real teaching situations, a lower-level inquiry strategy is employed.

The issue of guidance. Robert Yager writes: "How could real inquiry by individual and/or groups of students be 'poor pedagogy'??" While *real* is not defined, I think we can assume from what he has written previously that he means open, unguided inquiry and that he is confusing open (Level 4) inquiry with unguided inquiry by incorrectly equating them. Now, I haven't called open inquiry poor pedagogy. Quite to the contrary, I am aware of the evidence supporting inquiry learning and am a passionate supporter and user of the approach, but am simply questioning the use of one level of it only in one particular context; namely, open inquiry in upper secondary Science courses. What I have done is distinguished between the degree of direction and the degree of guidance provided to students and provided evidence for why unguided learning is poor pedagogy. In addition, I am not viewing guidance in the indirect, passive manner that Yager describes but rather in a direct, active way. I would welcome being shown evidence for unguided learning being superior to guided learning, but nobody has yet supplied such and I haven't been able to find any. Indeed, quite the opposite is the case, with support for guidance common in the literature. Let's consider some of this support.

Yager writes: "As long as one assumes that such questions [the questions students have posed] can be answered." Well, the evidence is that we can't make this assumption, and that students need guidance to ensure this point in a Level 4 (open) inquiry is reached. Chin and Kayalvizhi (2002) found that, in the absence of guidance, only 11.7% of the questions posed individually by Year 6 students for hands-on investigations were investigable. They concluded that pupils' "raw" questions do not seem to immediately lend themselves to practical investigations but that peer and teacher guidance can help to rectify this situation.

Further evidence for the value of guidance comes from the following:

- "Successful instruction nearly always includes performance-related feedback" (Brooks et al., 2005, p. 643).
- "My job is to guide students in their question asking, experimental design, and interpretation of results" (Dobson, 2008, p. 43).
- "Journals also give teachers a way to provide feedback to students to help guide their work" (Peters, 2008, p. 27).

- “The level of Instructor Support was the strongest independent predictor of student attitudes” (Martin-Dunlop & Fraser, 2008, p. 163).
- “Teachers play a critical role in open inquiry learning. Their role incorporates guiding, focusing, challenging, and encouraging students to engage in this type of learning” (Zion & Shedletzky, 2006, p. 23).
- “Students who receive frequent feedback about their ideas during the inquiry process tend to develop more complete understandings of science” (Donovan & Bransford, in Peters, 2008, p. 31).
- “Teaching an interactive inquiry course requires teachers who believe that students are capable of independent learning given proper guidance and support” (Lord et al., 2007, p.65).
- “What these classroom-based studies tell us is that learning to generate and use scientific explanations is a reasonable expectation in elementary science classrooms, but it does not happen automatically without specific scaffolds provided by the teacher (Gagnon & Bell, 2008, p. 61).
- In relation to the use of asynchronous, on-line forums to help students with open inquiry: “The results . . . indicate that students required assistance mainly with searching scientific information, finding experimental techniques and procedures, and phrasing inquiry questions” (Zion, 2008).
- “Most of the teachers initially described inquiry as a ‘student centered method of teaching’ (Lisa) where ‘students create their own knowledge and are responsible for their own learning’ (Roberta). . . . By the close of the semester, the idea of the teacher as a guide, or facilitator, was incorporated into their definitions” (Moseley & Ramsey, 2008, p. 53).
- “The importance of having an instructor who is comfortable and skilled in facilitating and guiding inquiry is clear. Without appropriate instructor guidance and facilitation, students may become frustrated because they are unable to reach understanding of the scientific concepts on their own” (Apedoe et al., 2006, p. 420). “Instructors must learn to walk a fine line between providing too much support and thus maintaining the teacher-centered nature of traditional science courses at the undergraduate level, and too little support that would leave students floundering without sufficient scaffolding” (p. 421).

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Peter Eastwell, Science Time Education, Queensland, Australia

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Bunsen Burner Danger

I recently conducted a class experiment with a Year 7 group using bunsen burners, and one of the youngsters set a rubbish bin on fire. I put out the fire and stopped the experiment. The students blamed an individual who responded that he had only discovered the fire! I have stopped doing all practical work with them because I feel it's too risky. Am I right? How do I proceed from here?

Yes, I would stop all practical work; but only for a limited period. You are likely to find that the class resent the lack of practical work and peer pressure might reveal the culprit.

Sue Howarth, Tettenhall College, UK

Wow, what a scary situation for all. I think I would quickly follow that incident up with a visit by a burn victim and/or a visit to a burn unit in a hospital. After reading about what happened in your lab, I myself might now have one or more of those people come for a visit at the beginning of a unit, or even before doing a lab with fire.

Kathy, Academy of Irving, Texas, USA

Perhaps use smaller manageable groups to demonstrate the experiments to the rest of the class. In this way, you can keep an eye on the action. The composition of the groups can rotate so that everyone has a chance. It may also mean that the students realize the result of dangerous action--less fun. As students “grow up,” you might consider giving more groups the opportunity to be “hands-on.” Please don’t give up on the lab work, as it is the essence of science and the exciting part that turns so many students on to it!

Anna Crowe, Cape Town, South Africa

Stopping experiments is like throwing away the baby with the bathwater! Accidents and pranks will always be there, and without evidence, you could destroy the child who is being blamed for the fire. It’s unscientific to conclude that he is responsible. Encourage him by complimenting that he noticed and communicated before worse could happen. Continue with experiments but use this situation as an example that safety precautions are not optional and pranks can be dangerous in science.

Francis Mavhunga, Swaziland

Appoint team captains for each practical.

Barb Howard, Rouse Hill Anglican College, Rouse Hill, Australia

By its very nature science requires experiments and, to some degree, risk and danger that has to be managed. If we remove the practical nature of the subject (we have already minimised it for the sake of safety) we are no longer doing science and cannot hope to give students an insight into this field of study. In this case a few adjustments to the room set-up (removing flammables such as paper from near the experimental area) would allow the experiment to proceed safely. Teachers need to be able to have the occasional crisis such as this in their classrooms, manage it, and continue to practise good pedagogy. Too often we throw out the educational baby with the crisis bath water when what is really a minor incident like this occurs.

The issue of overprotecting students in science has meant the elimination of many demonstrations and experiments that students found exciting and interesting. This has left us with a very bland curriculum that does not appeal to many and has lead to the small numbers studying the subject in modern times.

David Cuskelly, Queensland, Australia

In teaching science to students of all ages I have found that they all love to participate in practical activities. I set the safety rules and revise them before each practical activity (after all is said and done, how easy it would be if students remembered everything after being told only once). One of the stipulations of participation in any activity is their individual compliance with safety rules. This includes informing me immediately if any unplanned event occurs. I emphasise the need for us all to accept that we make mistakes but need not compound them by trying to hide the results of actions, deliberate or otherwise. All students should not be denied what must be such a motivating education because of the actions of one. The bin caught fire and therefore someone caused it, an answer is required to prevent a recurrence, but the important thing is to accept responsibility for ones actions. I have found that, as long as students are confident that their actions will, when the result of an accident or mistake becomes clear, be dealt with fairly and that no sanction will be imposed, they are willing to tell me so that the safety of everyone is our first priority. For those who choose to ignore the rules, exclusion from participating in the activity and becoming an observer so they are not denied learning usually brings about a rapid change of attitude.

Penny Kelliher, Leeming Primary School, Western Australia

I had a similar experience with students when doing a dissection. The initial response was certainly the same as yours, in terms of withdrawal of practical privileges. However, with negotiation with the students themselves, along with reasons as to why safety is important in a laboratory, it was possible to slowly reintroduce practical experiments; initially ones that were very short and VERY safe. Then as trust was re established the experiments became longer. The student who is under suspicion should be kept close to the teacher and always in view until he/she demonstrates that they are able to behave in an appropriate manner. Perhaps negotiate a contract with the individuals in the class about what are appropriate rules and behaviour and allow the students to determine the consequences; they are usually much harsher than teachers!!!!! Each student would then be required to sign and agree to the conditions negotiated, and have parents read and countersign the contract as well. This way the students actually own the contract (cliché I know but it does work.) A poster-sized copy of the agreed conditions and consequences should be made and placed near the entrance to the room. That way, in the event of any bad behaviour, it is easier to remind students that they made up the rules and agreed to abide by them. Some safety posters would also be of benefit.

Petra Robertson, Victoria, Australia

Laboratory Safety Guidelines

This section presents a series of 40 laboratory safety guidelines kindly provided by Dr James A. Kaufman, President, The Laboratory Safety Institute (LSI), USA. Please visit http://www.labsafety.org for further information, products, services, and publications.

#5 of 40. *Involve Every Staff Member in Some Aspect of the Safety Program and Give Each Specific Responsibilities*

You really need to find ways to get people involved. Students are people too, so don't forget them. There's a tendency to think that if someone is appointed safety coordinator, they have to do all the work for the rest of us. False! A coordinator is just that. He or she is not a "parent." Each person needs to be responsible for safety in general and for a specific part of the program in particular. Here's a list of a number of different specific assignments:

Lecture bottle gas cylinders	Chemical inventory
Highly toxic compounds	Heavy metals
Emergency response	Pyrophorics
Reference materials	Oxidizers
Alcohol inventory	Acids and bases

Fire equipment	Refrigerators
Flammables storage	Showers and eye washes
Specimen storage	Electrical hazards
Accident records	In-service training

Get the idea? Everyone has a job to do. Everyone participates. Take turns doing a monthly lab inspection. Take turns presenting a 5-10 minute safety topic at department meetings. Take turns telling the principal/superintendent about needed repairs (with the department head's permission)!

Who is going to be responsible for the department's laboratory health and safety bulletin board? How about the safety drawer in each lab? Who makes sure that the drawer is properly stocked?

Want to review your emergency procedures? There are more than a dozen common types of lab emergencies. Why not have a different employee/student conduct the review at the monthly staff meeting?

Who does your chemical hygiene plan review? The CHO? The safety committee? Give it up! Give it to 3, 4, or 5 members (students) of your department and treat them to the CHP review luncheon. Don't forget to give your boss, or your boss' boss, the leadership opportunity to send the reviewers a thank-you note.

The best safety programs are the ones that get everyone most involved. Safety is not a spectator sport (sounds good; I'll have to remember that)! How do you get people involved? Let's hear about what you're doing?

Further Useful Resources

Encyclopedia of Life (http://www.eol.org/) A new project aiming to develop an "ecosystem of websites" that documents all species of life on Earth.

Science Buddies (http://www.sciencebuddies.org) Science fair project resources for students and teachers, including ideas for topic selection and a timeline.

Center for Inquiry-Based learning (CIBL) and TASC (http://www.ciblearning.org/) The CIBL & TASC (Teachers and Scientists Collaborating) offers inquiry exercises, for Years 4-12, that require few purchased materials.

Physics Movies (http://www.nicholls.edu/phsc/physics/movies/) Over 60 movie clips to use for teaching physics.

Biography Project (http://www.sacnas.org/biography/) Short biographies of over 70 contemporary Chicano and Native American scientists. May be used as a segue or introduction to a topic, and to engage students in the cultural and personal influences on scientific work.

Connecte²d Teaching: Extreme Event Design (http://mceer.buffalo.edu/connected_teaching/index.html) Links the study of earthquakes and engineering design to middle school science, mathematics, and technology to help students understand how the scientific phenomena associated with earthquakes affect humans and their decisions.

New Scientist: 2007's Best Online Videos

(http://www.newscientist.com/article/mg19626352.800-watch-this-2007s-best-online-videos.html) A collection of online videos for 2007.

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