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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Detecting Mobile Phone Signals

An unshielded electronic digital balance can be used to demonstrate that a mobile phone emits electromagnetic radiation. Simply turn on and zero the balance, turn on the phone, hold it near the balance, dial a number, and observe the alternating values on the digital balance display. Links can be made to other possible effects of mobile phone signals, as illustrated by the requirement that all mobile phones be turned off during certain phases of air travel.

Source: Shaw, M. (2007). It's your call: Make the invisible visible. *The Physics Teacher*, *45*, 456.

Science Story

The stories in this regular section of *SER* may be used to enrich lessons and make them more interesting.

First use of Radioactivity

The first use of radioactivity may have been as a tracer, and by a group of physicists living together in a boarding house in England in the 1920s. Suspecting that the landlady was reusing uneaten food from their plates to make the weekly stew, they sprinkled some low-level radioactive powder over their leftover food. Sure enough, their suspicions were confirmed, as the next stew was slightly radioactive.

Source: Kruszelnicki, K. (2006). *It ain't necessarily so . . . bro*. Sydney: HarperCollins.

A Novel Approach to Understanding the Process of Scientific Inquiry

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Abstract

Many of the basic concepts involved in the process of scientific inquiry can be represented by analogy to a simple game called Battleships. The same processes used in this child's game demonstrate what role hypothesis generation and testing play in the search for truth in nature. The analogy can also be extended to demonstrate how scientists can unknowingly be led to faulty conclusions about the structure and patterns of nature.

There is a rather simple children's game called Battleships that requires only two pieces of paper and two pencils. Each player grids his or her paper with an identical pattern of columns (A to Z) and rows (1 to 26). Each player is allowed a particular number of certain "ships," each of which is defined by connected squares. The bigger the ship, the more squares it occupies (e.g., an aircraft carrier would be seven connected squares, a battleship six, a cruiser five, and so on). A person might start the game by calling out for a square, say P-12. His or her opponent then responds by announcing whether this was a "hit" or a "miss." The first player to hit all the squares of their opponent's ships wins.

This game has much in common with the process of scientific inquiry. By analogy with the game, one might perceive nature's hidden truths as ships arrayed in some complex pattern, and it is the role of scientists to find out what these patterns are. Probing for patterns in nature is done by experiment. Some patterns are obvious from inspection, while others require intricate schemes to decipher.

In the early stages of the game of Battleships, calls are random (e.g., P-9, B-13, Q-12) until hits are recorded. This stage has similarities to inductive science; often given short shrift by the self-appointed guardians of the "scientific method." Inductivism can play an important, though not necessary, role early in the process of scientific discovery. For example, an earth scientist might come up with an idea, such as continental drift, by staring at a globe in the corner of his office and noting, as Alfred Wegener (1915) did, the fit of the African and South American coastlines--but you must first have a globe. Although having some observations is a good place to start from, science philosophers such as Karl Popper (1959) argue that one can generate a hypothesis independent of observations.

In Battleships, when hits are recorded they are followed by "what ifs"--what if there are connected squares that are part of a larger ship? Nearby coordinates are called out, and the first hint of a pattern starts to unfold. A true inductivist would continue to call out numbers randomly until all the squares are chosen and then identify a pattern to the ship placement. However, using deductive reasoning one can postulate, or hypothesize, a pattern based on the initial random probing, and test the hypothesized pattern by calling out B-14. If B-14 comes in as a hit, the player has achieved what Gottfried Leibnitz would call "the greatest commendation of a hypothesis (next to truth), if by its help predictions can be made even about phenomena not yet tried" (cited in Kneale, 1967, p. 29). Simple? Yes and no. In 1973, Nobel laureate Harold Urey suggested that a large meteorite hit the earth and killed the dinosaurs. Seven years later, Berkeley professor Walter Alvarez (Alvarez, Alvarez, Asaro, & Michel, 1980) finds high levels of the rare element iridium most commonly found in meteorites, at the paleontologically defined boundary thought to coincide with the extinction of the dinosaurs. *Quod erat demonstrandum*, right? Well, not really--many at the time questioned the meaning of the discovery by Alvarez. For example, could the iridium be concentrated at the existing boundary by ground waters unrelated to a meteorite impact? Here the tightly-scripted game Battleships must be manipulated to parallel the vagaries of scientific inquiry. Imagine, for example, that in your game of battleships the coordinates you read out pass through some unseen filter that, unknown to you, reroutes your choices, so that your call of B-14 is recorded as Q-19 and your call yields a hit when it should have produced a miss. Philosophy-of-science writers like Karl Popper prefer to avoid such gray areas. Rather, they would like a theory to be proposed and a test performed that either is consistent with it or falsifies it. In other words, a theory holds until one decisive test of its predictions fails. But who defines what is "decisive"?

Filtering which results in an erroneous test can either be systematic or accidental. The systematic filtering is the most dangerous because repeated experiments will produce repeated incorrect conclusions. In my own field of structural geology, for example, granite mylonites--rocks with distinctive "augen," or "eyes," of white feldspar minerals in a sea of dark, fine-grained minerals--were once thought to be the distinctive product of intense frictional grinding and thus indicative of earthquakes. Detailed microscopic and theoretical studies of these rocks later showed that they actually deformed ductily, like stretched taffy, and thus they have no relation to earthquakes. Clearly, there existed a systematic filter that corrupted tests for the seismogenic behavior of many faults.

Even if there is no systematic filtering effect, your experiment can mislead you because it is too narrowly restricted--either by your lack of imagination or some inbred, heartfelt, gut feeling that you "understand" nature. Such a pre-experiment prejudice can often lead to a selecting of calls that are likely to yield a pattern that you interpret to be consistent with your cherished hypothesis about the shape of the ships. Human nature is such that we tend to like the theories in which we have our time and reputation invested. Max Planck once wryly commented that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (cited in Kuhn, 1970, p. 151). This kind of restricted thinking in the scientific game of Battleships results in making the same calls you've made before, because the ships were there in the past. However, if you envisage several possible ship configurations in advance and pick the best call that can be made to distinguish between them, you are then much more likely to discover unpredicted patterns that may exist in ship placement than by just testing for a single ship configuration--and thus the multiple working hypothesis model of T. C. Chamberlin (1897).

There is commonly an erroneous assumption that scientists go about gathering facts objectively until they have overwhelming evidence that “proves” a particular scientific principle. Scientific discoveries are often made beginning with this process, but little advancement can be made without application of the process of proposing hypotheses and testing them. In a classroom setting, the best way to convey how this process might work in the Battleships analogy is to draw a grid on the blackboard. The grid doesn’t need to be extensive (e.g., A through G on one axis and 1 through 7 on the other). The instructor chooses a pattern of squares that is unknown to the students. This can be something simple like a cross or an X shape. The squares don’t have to be connected, although it works best for demonstration purposes if they are. Ask students to pick various squares, one at a time. To demonstrate the approach that is commonly thought to be the “scientific method,” have the students call out a series of grid squares until enough have been called to expose all the grids making the pattern shape you have selected. A shape will emerge if enough squares are called out. This is a simple inductive method, which can produce results, but is limited to the number of possible grids that can be called. In nature, that would be like measuring everything possible to identify patterns--in other words, an endless process that might advance our understanding of natural processes or might just waste our valuable time.

On a second grid, again select a pattern unknown to students. Have them, as before, randomly select grid squares, but this time when the first hits are made the instructor could hint that the shape might be the same as before (which it is not) and have the student select a grid square consistent with the previous pattern. Here the instructor should point out to the students that they are developing a hypothesis and that it can be tested simply by choosing a single square. Since the instructor has chosen a new pattern, the square the students pick should record a miss. So at this point the instructor can discuss what some philosophy of science writers call falsification--that is, the students hypothesized a certain shape and the ground testing of that hypothesis showed it to be incorrect. Now have the students continue with a few random selections until one or more hits are made. At this point have the students develop a hypothesis. In fact, have two or more students develop different hypotheses--again, the concept of multiple working hypotheses. Have the students agree as to where the next best square selection might be made to distinguish between the various hypotheses. After the selection is made, have them discuss which hypotheses are still viable and which ones should be discarded. Continue this process with accompanying discussion until the instructor feels they have successfully communicated to the students what is essentially the process of scientific inquiry.

Scientific inquiry, though, is not limited to some imaginary 26 by 26 grid. Even with the best intentions, we can never perform enough experiments to completely describe nature's patterns. We are always extrapolating from a limited number of calls. Some extrapolations are certainly better founded than others, but even the best have some level of ambiguity. Furthermore, some experimental results are not clear; but are obfuscated by poor design, poor communication, or intent. This lack of clarity creates another kind of accidental filter that is equally detrimental to identifying patterns.

In the paper game of Battleships, one eventually gets to find out where all the ships were placed. Scientists aren't so lucky. Karl Popper (1959) commented that, in valid scientific inquiry, only testable hypotheses have meaning, and even a poorly supported hypothesis is acceptable as long as a test can be constructed which could show it to be wrong. Moreover, he felt that no theory should be considered "true" in the strictest sense. From this it follows that commonly used words like *prove* and *confirm* are inappropriate language to be applied to a hypothesis, or a test of a hypothesis.

Since a theory can never be proved, one might conclude that truth in science is by plebiscite, which is as likely a way of defining "truth" as twelve jurors are likely of determining guilt beyond a reasonable doubt. As with guilt, truth in science by consensus can be, and often is, wrong. Yet, even if the search for the ultimate truth in nature is indeed futile, scientist wouldn't dream of giving up their quest. We may never hit all of nature’s battleships, but at least we can narrow the field of their locations--and, it is hoped, leave the world a little more interesting a place than we found it.

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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?

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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 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 that was helping other students do their homework. He would tutor students during class. He would lead the class in understanding laboratory applications. He would volunteer to answer questions in class.

I knew immediately that I had failed Brian. It took awhile 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. Soon I began including oral presentations, group projects, concept maps, and oral quizzes. I kept close track of student grades and, if a student was failing, I considered what I could do to address his or her 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 .

Way Back When

Think of us, in this world
Our freedom of speech so widely heard.
Our trains, buses, trams, and cars
Always known to get us far . . . But . . .

Life was simple, way back when
Our problems were never thought of then.
The old brick roads, and candles bright
Were used to illuminate the night.

No televisions or computer games
Flushing toilets, were only names.
Air-conditioners were simply unknown
On a boiling day, you sweltered alone.

Fewer cars, pollution was rare

Hurricane

Light up the sky as a yellow glow
splits the horizon in half.

The sound of a train
coming closer and closer
with no track to be found;
an engine out of control and
a world out of control.

run . . .where do we hide?
An underground cellar, a closet, a bathroom
Or a room with no windows.
It’s only a matter of minutes before this train
Comes into the station.

An earie sensation of electrical impulses

They lived to breathe the clean pure air.
A simpler life for all, of that time
A better, safer world--sublime!!

Dylan Crowe, 11 years
Australia

And static electricity fills the atmosphere.
The whirling, swirling funnel speeds up, slows down
And changes direction on a dime.

Will we make it through?
What will be left of us and the world
We knew a just moments ago?

Silence again.

We venture outside to see a universe we usually only
See in our nightmares.
Total destruction around us; cries for help from
Demolished homes.
A bicycle in our tree.

Our property untouched . . .
Our lives forever changed.

Adam Herman, 15 years
Australia

Genomics Analogy Model for Educators (GAME): VELCRO® Analogy Model to Enable the Learning of DNA Arrays for Visually Impaired and Blind Students

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Abstract

Although members of the general public have often heard of the terms *genetic engineering* and, more recently, genomics, they typically have little to no knowledge about these topics, and in some cases are confused about basic concepts in these areas (Lewis & Wood-Robinson, 2000). There is currently a need for teaching models to explain concepts behind genomics. Additionally, almost nothing exists for teaching the visually impaired and blind about genomics. The purpose of the Genomics Analogy Model for Educators (GAME) approach is to convey the basic concepts of genomics to students using analogies and inexpensive materials that students encounter in their daily lives. In recent articles, we have introduced the GAME approach with several of its components. In this article, we present the concept that a VELCRO® analogy model could be used to enable learning of the concepts of DNA microarrays for both fully-sighted and potentially visually impaired students. Classroom activities using VELCRO® are proposed as a teaching module to explain how DNA microarrays work. In summary, differentially shaped VELCRO® pieces fixed to a solid base are used to represent the array and the complementary pieces of VELCRO® are used to represent the cDNA. Students can use this approach, for example, to explore expression patterns of "genes" between experimental groups. We term this teaching approach the VELCRO® Analogy Model (VAM).

To read the full text of this article (12 pages), please **click here**.

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.

Melting

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1. (a) Indicate if each of the following involves melting, dissolving, neither, or that you are not sure: Placing sugar in hot water, a wax candle left in a closed car in the hot sun, adding salt to soup, ice-cream after being taken out of the fridge, margarine placed in a hot pan, chocolate in your mouth, detergent added to water, sugar placed in a heated pan.

   (b) What is it about a phenomenon that allows you to describe it as melting or dissolving?

   (c) Some students think that sugar melts in water, while others believe that sugar dissolves in water. To some, melting and dissolving are the same thing. What do you think?

Comment. A wax candle left in a closed car in the hot sun, ice-cream after being taken out of the fridge, margarine placed in a hot pan, and sugar placed in a heated pan involve melting. Placing sugar in hot water, adding salt to soup, and detergent added to water involve dissolving. Chocolate in your mouth is a tricky one, because it might involve both melting and dissolving; melting due to our body heating it and then dissolution in our saliva. Part (c) seeks to identify those who possess the very common alternative ideas that melting and dissolving are the same thing and that sugar melts in water.

2. Mert, Sevim, and Ahmet are discussing whether the mass of an ice cube will change on melting.

   Mert thinks that ice **loses** mass on melting.
   Ahmet believes ice **gains** mass on melting.
   Sevim thinks the mass of water and ice will be the **same**.

   Who do you think is right? Explain why you think in this way.

Comment. Sevim verbalizes the correct answer.

3. Which of the following statements about the mass of water in a covered glass is correct?

   (a) The mass of water is more when it is in a solid state.
   (b) The mass of water is more when it is in a liquid state.
   (c) The mass of water is more when it is in a gaseous state.

(d) The mass of water is the same in all states.

Please explain your choice.

Comment. Choice (d) is the correct statement. Some students might think that the mass of a substance changes according to its physical state, and their reasons can vary.

4. An ice cube melts completely and turns into water. For each of the following statements, please indicate if you agree, disagree, or are not sure.

   (a) The mass of the water will be greater than the mass of the ice because heat energy goes into the ice.
   (b) The water will have the greater mass because its density is greater.
   (c) The mass of water will be the same as the mass of ice because no mass has been added.
   (d) The water will have the greater mass because its volume is greater.
   (e) The ice will have the greater mass because its volume is greater.
   (f) The mass of ice will be the same as the mass of water because their densities are the same.
   (g) The ice will have the greater mass because it is solid.
   (h) The ice will have the greater mass because its density is greater.

Comment. Choice (c) is the only correct statement. This question might be useful to assess students' progress after instruction.

Source: Kabapınar, F. (2007). Students' ideas about changes in mass associated with melting. *The Science Education Review*, *6*, 132-138.

Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

Podcasting

Podcasting is the distribution of audio and video files for viewing on a computer or handheld electronic device. The most basic podcasts are simple audio podcasts, which Lucking, Purcell, and Christmann (2006) recommend for use in the school environment because MP3 players are quite common whereas there will be fewer opportunities for students to access video playback devices.

While lectures are commonly recorded at the university level, in a middle school, say, one might record:

- Selected readings (especially appreciated by students with reading difficulties).
- Guest speakers.
- Final presentations.
- A guided nature walk
- Description of the night sky.

To create a simple audio podcast, connect an inexpensive microphone to a computer and record your voice using, for example, the Microsoft Windows Sound Recorder utility. More advanced free utilities, such as *Audacity* (n.d.) and *GarageBand* (2008), will allow you to do additional things that include the addition of sound effects and music.

Reference

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Hands-On Science: Does it Matter What Students' Hands are on?

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Abstract

Hands-on science typically uses physical materials to give students first-hand experience in scientific methodologies, but the recent availability of virtual laboratories raises an important question about whether what students' hands are on matters to their learning. The overall findings of two articles that employed simple comparisons of physical and virtual materials suggest that virtual materials could be an effective and efficient alternative to physical materials when teaching with explicit instruction and discovery learning methods. (This paper is a summary of Klahr, Triona, & Williams, 2007 and Triona & Klahr, 2003)

How should we teach science? Traditionally, the primary method to teach science was having students read textbooks and listen to lectures in which major scientific findings were described as facts and the particulars of scientific methods and procedures were often minimized or omitted entirely. In contrast, hands-on science teaching brings the scientific methods used to produce new scientific knowledge to the forefront. In hands-on science, students' concrete, kinesthetic actions are related to abstract concepts and these activities tend to increase student motivation and engagement (Flick, 1993; Haury & Rillero, 1994).

Two recent developments in science education motivated the current research. In California, policymakers ignited controversy when they specified how much hands-on science should be in the curriculum (Woolf, 2005). Starting as a 25% maximum, the policy was eventually switched to a 25% minimum. The other development is the increasing access and quality of computer-based, "virtual" materials for science education (e.g., Davis, 2007; Dillon, 2006). These convergent developments raised an important question: Does it matter whether the hands-on activities are executed with physical or virtual materials?

When comparing physical and virtual materials, there are at least three potentially important dimensions to consider: (1) What is being taught? Is it a process skill, such as creating controlled experiments or filling out tables of data, or is it particular facts and concepts, such as the speed of light or the structure of the carbon atom? (2) How is it being taught? Where on the broad spectrum from explicit instruction to discovery learning is it? (3) Is it hands-on or hands-off instruction?

Because there are so many different aspects of hands-on science instruction (Flick, 1993; Hmelo, Holton & Kolodner, 2000), simple comparisons were needed to compare the effectiveness of physical and virtual materials. Here we summarize two papers (Klahr, Triona, & Williams, 2007; Triona & Klahr, 2003) that begin to answer how the type of hands-on science influences different kinds of learning."

Learning to Design Good Experiments With Explicit Instruction

Many studies have found that elementary students often design flawed experiments in which they change multiple things at once, thereby making it impossible to determine which change caused the effect (e.g., Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Schauble, 1996). However, directly teaching elementary children how to control extraneous variables can be very effective and students can then transfer this skill to other experimental situations (Chen & Klahr, 1999).

By developing a virtual version of those physical materials, we could compare students' learning with physical materials to their learning with virtual versions of the same materials. The virtual materials mimicked the physical materials as closely as possible (see Figure 1) to ensure that, if there was a difference, it was the version of material making the difference.

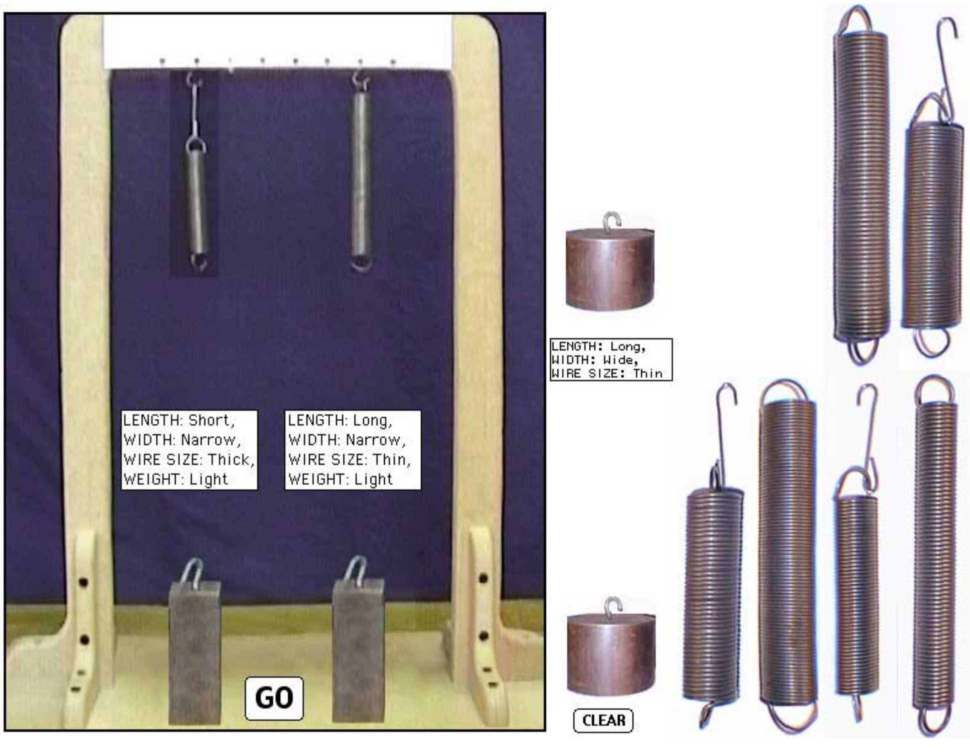

Figure 1. Shown here is the computer interface that children assigned to the virtual materials condition used to design comparisons of different types of springs during the pretest and posttest and that was used for their instruction on creating comparisons that controlled extraneous variables.

In our first study comparing physical and virtual materials (Triona & Klahr, 2003), we randomly assigned 92 fourth- and fifth-grade children to use either physical or virtual materials to design comparisons of different kinds of springs both before and after receiving explicit instruction about how to design good comparisons. A week later, in order to determine whether students could successfully transfer their new skill to another context, all children used physical ramps to design additional experimental comparisons.

We found that, on a variety of measures of learning, there was no difference in the performance of children trained with physical materials and virtual materials; both groups showed similar gains in their learning to design good experiments (from 20% pretest to 60% posttest and transfer). Children in the virtual materials training group could have been at a disadvantage during the transfer phase because they changed material type (from virtual to physical) and domain, while the physical materials training group changed only domain. However, there was no significant difference between groups. Moreover, type of material did not influence children's learning from their comparisons about the effects of the variables, nor in whether they verbally explained the importance of controlling variables. These findings suggest that instruction using either physical or virtual materials is equally effective at teaching elementary school students' how to design unconfounded experiments, at least when using explicit instruction.

Learning the Effects of Variables with Discovery Learning

But perhaps the impact of physical versus virtual materials would be different in a discovery learning context? Our second study (Klahr, Triona, & Williams, 2007) addressed this issue. We compared physical and virtual materials in a context in which middle school students attempted to learn about a novel domain while using a discovery method. In this study, 56 seventh- and eighth-grade students built and tested several "mousetrap cars" (see Figures 2 & 3). These cars have several factors that influence the distance that a car will travel once it is released. Students were given the engineering task of designing a car that would travel the farthest--they were not asked to design unconfounded experiments. Half of the students built and tested their cars virtually while the other half used physical materials. To examine the influence of the virtual materials taking less time to build and test, the groups were further divided with some having 20 minutes to build and test cars while the others were asked to build and test six cars, regardless of the time it took.

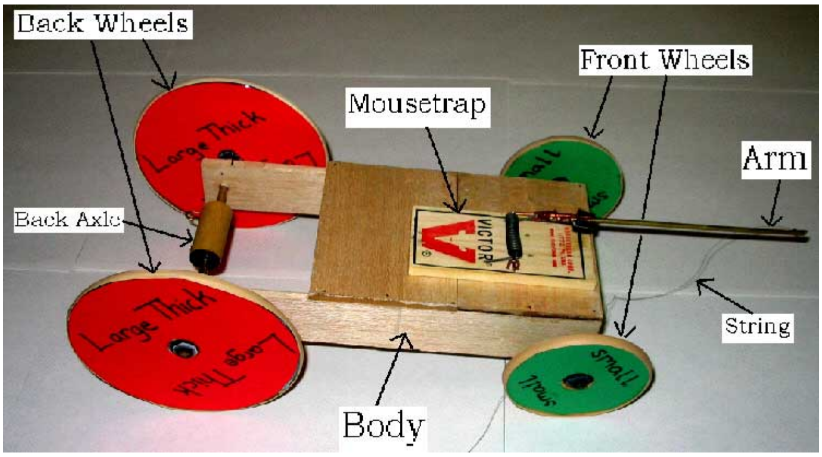

Figure 2. Mousetrap car built using the materials that children assigned to the physical materials condition used.

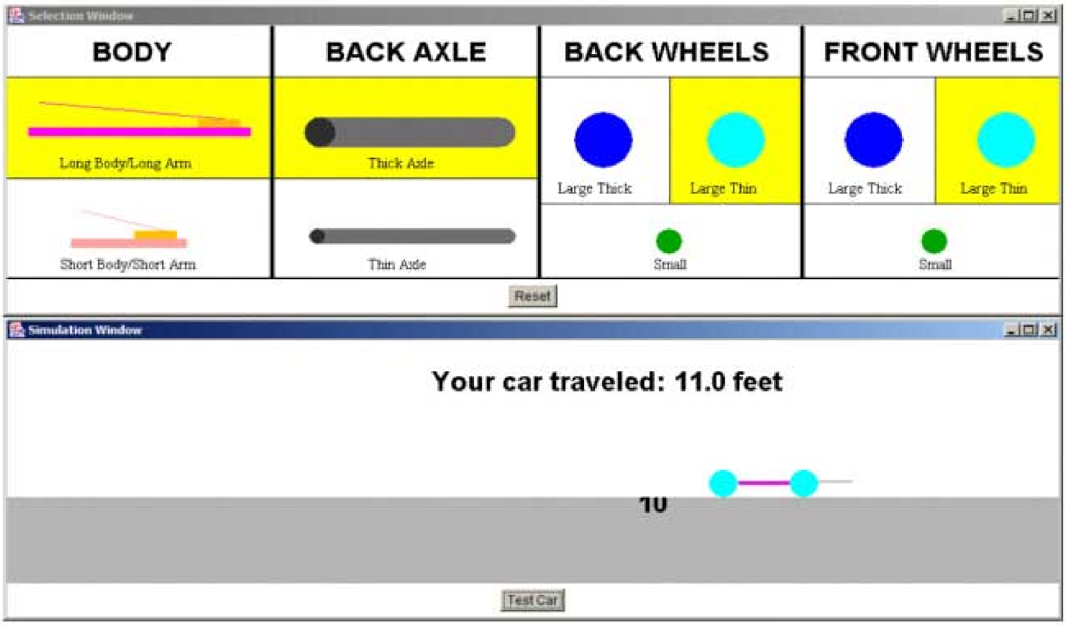

Figure 3. Computer interface used to build and test mousetrap cars by children assigned to the virtual materials condition.

How did students' ideas about the effect of each car feature (i.e., size of wheels, wheel thickness, length of body, axle thickness) change after designing and testing their cars? Students from all groups improved in their accuracy of car feature effects regardless of whether they were using physical or virtual materials, built 6 cars, or worked for 20 minutes. In particular, student learning for all groups was most pronounced for the four causal variables (from 51% correct to 91% correct). However, there was no significant change for the non-causal variables in any of the groups, which concurs with prior research that finds identification of non-causal variables is especially difficult (Kuhn, Schauble, & Garcia-Mila, 1992).

As expected, students were faster at building and testing the virtual cars than the physical cars, but despite the reduced time spent by children who only built six virtual cars, they learned a similar amount. Equally interesting was the result that students who built virtual cars for 20 minutes--testing many more cars than the other students--did not learn more than students who built and tested fewer cars.

In summary, children showed similar improvements in their understanding of the causal features of mousetrap cars regardless of whether they used virtual or physical materials. These findings suggest that "hands-on" science using virtual materials, which can also be more efficient (i.e., take less time and resources to develop and use), could be an effective alternative to the use of physical materials.

Conclusion

The incorporation of technological tools already plays an important role in science classrooms (Davis, 2007) and the current studies suggest that virtual materials could be a viable option. However, there might be particular domains (e.g., life sciences) that require experience with authentic, physical objects rather than their virtual equivalents (Apkan, 2002; Eberbach & Crowley, 2005). Much still needs to be learned about the influences of different instructional materials on student learning.

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Ideas in Brief

Ideas from key articles in reviewed publications

Blogs

Journal writing (e.g., learning logs, learning journals, think journals, and reflective journals) have been widely used by educators, although less so by science teachers. A blog (an abridgment of the term web log) provides an on-line journaling experience that Johnstone (2007) suggests can play a useful role in science education, including being used to record students' progress with extended experimental investigations.

Blogger (2008) and *Edublogs* (2008) are two free, user-friendly blogging services that a student can use to set up a blog in only 5 minutes. A blog can play the role of a laboratory, or log, book for keeping a record of experimental work, and can even adopt the style of a formal experimental report. A blog can also be commented on by the teacher, other students, or anyone else with the password.

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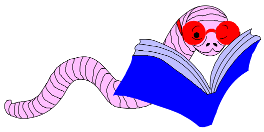

Research in Brief

Research findings from key articles in reviewed publications

Views of Science Graduates Working Outside Their Discipline Specialisation

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If we accept that many students are not enthusiastic about pursuing science degrees and, in general, work and science practices are changing, then we need to revisit the purposes and nature of undergraduate science degrees. Rodrigues, Tytler, Darby, Hubber, Symington, and Edwards (2007) asked Australian science graduates, employed in positions outside their discipline specialisation, for their rationale and reasons when choosing to study science at university. The project also tried to determine the capabilities and expertise these students employed in their personal and professional lives. The project tried to see how these aptitudes and proficiencies related to their science undergraduate education. The need for this information stems from two key aspects. First, about one half of science graduates occupy positions outside their discipline and second, it is likely that we will need more science graduates in decision-making positions in government and industry.

The project participants suggested that motivating factors when opting for science degrees were related to personal interest, familiarity of science ideas from high school, and parental and social expectations. Rodrigues et al. (2007) suggest parental views of job opportunities and success in school science are more influential than a well-developed interest in science, when it comes to deciding the tertiary area of study for science graduates who are working in non-specialist positions. While this may not apply to science graduates who opt for, and stay with, careers in their science areas, it is a potentially significant finding if we want science degrees to attract a wider range of students.

Project participants reported two common complaints with respect to their science educational experience. They suggested that career advice prior to beginning university was deficient. They also stated that throughout their training, the relevance of the science was not promoted, nor indeed was the use of science in real work milieus. We need to break down the perception that science degrees only lead to specialist careers within laboratories or the field. Instead, we need to show the diversity of employment opportunity. The career paths of the project participants were varied, but almost all gained formal qualifications in addition to their BSc degree. The project findings suggest that science degrees must include problem-solving and communication skills, as well as foster an understanding of science within its social and ethical context.

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Students' Ideas About Changes in Mass Associated With Melting

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Abstract

This paper reports a study on elementary students' ideas regarding changes in mass associated with melting. An open-ended probe was designed and distributed to fifth-grade students (n = 230). In addition, 50 students were asked their reasons behind predictions on mass change. The written responses indicate that, despite conventional teaching, students have difficulty understanding conservation of mass. Although students' predictions were similar, individual reasons for those predictions differed. In some cases, students used similar reasons for different predictions. Finally, the results of the study highlight misconceptions that have not been reported previously.

Research indicates that students have difficulty understanding conservation of mass. The reasons behind this difficulty vary. Driver (1985) points out that students perceive physical change as disappearance of the substance, and evaporation, sublimation, and dissolving are common examples (Andersson, 1990; Bar, 1989; Bar & Galili, 1994; Johnson, 1998; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Stavy, 1990). Another reason for the difficulty seems to be related to students' perceptions of the nature and physical state of the matter on change. Studies indicate that students aged 9-13 years tend to regard a gas as having no mass, or less mass compared to the solid or liquid form of the substance (Mulford, 1996; Prieto, Watson, & Rodriquez, 1993; Renstrom, Andersson, & Marton, 1990; Schmidt, 1997; Sere, 1986; Stavy, 1988, 1990). Studies also show that students imagine gases as having the property of negative mass. In other words, they think that the more gas that is added to a container, the lighter the container becomes (Driver, 1985; Renstrom, Andersson, & Marton, 1990). With such misconceptions, students will unlikely conserve mass in physical or chemical change involving gases.

Students' reasoning regarding conservation of mass is also influenced by their atomistic/particulate ideas. Piaget and Inhelder (1974) suggested that the ability to conserve mass develops as students start to construct particulate models of matter. This assertion has not been supported by later research (Adey, 1976; Holding, 1987; Selly, 1979). For instance, Holding (1987) found that some students who imagined sugar dispersed as very small molecules did not conserve mass because they regarded such tiny molecules as having negligible mass or being less dense. Additionally, students also think that atoms do not have mass or that the number of molecules is not conserved during physical changes (Andersson, 1990; Gabel, Samuel, & Huhn, 1987). These particulate ideas clearly do not help students to conserve mass in physical changes.

Even though a substance does not disappear from their sight, students fail to conserve mass on melting (Krnel, Watson, & Glazar, 1998; Stavy, 1990). The majority of students think that solids loose mass on melting (BouJaoude, 1991; Osborne & Cosgrove, 1983; Stavy & Stacher, 1985). Since melting does not involve gases, these students' beliefs seem to be supported either by their conception of substance or their atomistic view of matter. Students might believe that solid substances stick together better than when in a liquid form and are hence heavier (Lee et al., 1993). Also, students do not conserve number or mass of atoms (or molecules) by attaching physical properties to them (Ault, Novak, & Gowin, 1984; Griffiths & Preston, 1992). For example, they think water molecules are largest and the heaviest in the solid state (i.e., when they form ice) (Lee et al., 1993; Krnel et al., 1998; Pereira & Pestana, 1991). Thus, students are likely to believe ice weighs more than water.

It appears that many students do not conserve mass in physical changes, and that their reasoning differs, even if they support a similar view regarding conservation of mass. In the area of the conservation of mass involving physical changes that include evaporation, sublimation, and dissolving, melting seems to have attracted the least research attention. Thus more research would help uncover the origins of student ideas concerning mass changes associated with melting. This study therefore aimed to find out whether elementary students who received conventional teaching on physical changes conserve mass on melting and to uncover their underlying reasoning. In this way, students' incorrect ideas concerning melting that result from science education can be pinpointed and teaching can be redesigned accordingly.

Research Questions and Methodology

The aim of this study was to investigate elementary students' ideas related to change in mass during the melting process. In order to do this, two research questions were addressed: Do students conserve mass during the melting of ice? How do students justify their ideas (correct or incorrect) related to mass change associated with melting?

A total of 230 Turkish elementary students aged 11-12 years took part in the study. Students were chosen from five different state schools. An open-ended probe that asked students to predict whether the mass of an ice cube changes on melting, and to justify their prediction, was used in the study. The probe was distributed to students after their conventional teaching on melting. In Turkey, students meet the concept of melting for the first time in their elementary education (at the age of 11 years) and under the subject "The Effects of Heat on Matter." Conventional teaching of melting involves teaching terminology (definition) and rules (mass is conserved on melting). The teaching method used is mainly teacher-centered, with the teacher explaining, in both macroscopic and submicroscopic terms, what melting is and how it happens. In this sense, the teaching is based on a transmission of knowledge view of learning.

After students responded to the written probe, 50 students were interviewed individually to determine the reasons behind their predictions. Interviewees were chosen so as to represent different reasoning related to mass change on melting. All interviews were audio taped and fully transcribed. Students' open-ended responses were analyzed in an ideographic way (i.e., students' responses were analyzed in their own terms rather than categorizing them according to pre-determined categories). The categories were therefore developed as the data analysis proceeded. After students' responses had been categorized, frequency distributions were calculated. To ensure reliable and valid analysis, random samples of the coding were independently checked by another coder, and 94% reliability was achieved. In analyzing the interview transcripts, particular consideration was given to aspects such as the following: What kind of reasoning do students have for their mass prediction? Do they draw upon the particulate model in order to justify their answers and how do they draw upon it when they were cued to use it? In what ways do they relate the concept of mass to the concepts of volume, density, and heat?

Results

Table 1 shows students' predictions about the change in mass of ice on melting. Less than one half of the students (40%) believed the mass would stay the same during melting, 57% did not conserve mass on melting, and the remaining 3% gave an uncodable response or no response at all. Of the students who did not conserve mass on melting, the majority imagined that the mass of ice would decrease during melting while the rest predicted an increase in mass.

Table 1
Student Responses to the Probe on the Change in Mass of Ice on Melting

Student Response	Number of students (N = 230)
Misconceptions	
The mass **decreases** during melting	74 (32%)
The mass **increases** during melting	57 (25%)
	(Total: 131 [57%])
Scientifically acceptable response	
There is **no change** in mass during melting	93 (40%)
Uncodable/no response	6 (3%)

Students' written and oral responses indicated that although their predictions were similar, the underlying reasons varied. Table 2 presents students' reasoning about mass change on melting. The prediction that ice would have more mass than water was supported by seven underlying reasons. Some students appeared to generalize that the mass of solids is always more than the mass of liquids. Interviews indicated that these students either referred to the position of solids (at the bottom) in water or their feelings of carrying a solid to back up their concept of "heavy solid." Apparently, these students drew their reasoning heavily from perceptual features.

Perceptual cues formed the basis for another line of reasoning. This group of students compared the volume of ice with that of water and believed that the volume of ice is more. They therefore decided that ice would weigh more than water. Some of these students supported their reasoning using the example of volume increase (expansion) during freezing. Apparently this line of reasoning not only stems from perceptual cues concerning volume changes on melting, but also from students' failure to differentiate the concepts of mass and volume. According to these students, bigger volume means more mass. There seems to be a similar relationship between the concepts of mass and density. According to their written responses, some of the students thought that density of ice would be greater than that of water and thereby would weigh more. Upon further probing, they explained that ice is solid and therefore denser than water. When they were asked if this is the case for every solid and its liquid form, some responded to the question positively without any hesitation whereas others were ambivalent.

Table 2
Student Reasoning About the Change in Mass of Ice on Melting

Prediction	Type of reason	Underlying reason
Ice has more mass	Perceptual	Solids are heavier than liquids.
		Ice is heavier than water, solids sink in water.
		Volume of ice is more than that of water.
	Conceptual	Density of ice is more than that of water.
	Particulate	Solids are/ice is closely-packed.
		Ice has more particles than water.
		Particles of ice are less energetic.
Water has more mass	Perceptual	Density of water is more than that of ice.
		Water is heavier than ice as ice floats on water.
		Volume of water is more than that of ice.
	Conceptual	Heat is a substance and has mass/weight.
	Particulate	Particles of water are more energetic.
The mass of ice is the same as the mass of water	Perceptual	No mass is added or removed as ice turns into water.
	Conceptual	Mass does not change during melting.
		Mass is always conserved.
	Particulate	Particles of ice and water are the same

Another line of reasoning offered by students who predicted a decrease in mass on melting was related to students' ideas concerning the particulate nature of matter. They thought that molecules of a solid weigh more than water. Some of these students assumed ice would have more molecules than water, and thus they predicted the mass of ice would be greater than the mass of water. On the other hand, some students based their reasoning on molecular movement; they thought molecules with more energy weighed less. According to interviews, these students imagined that water molecules move faster, and therefore would have less mass, than ice. Students believed energy made the molecules lighter. Another reason was related to the movement and balance of molecules. Students believed molecules in ice cannot move freely. Thus their molecules are static and have more mass, whereas water molecules are not static and have less mass. These students believed that movement of molecules determines the mass, even if the molecules are from the same substance.

Other students predicted an increase in mass during the melting of ice, using five underlying reasons. According to students' written and verbal responses, the majority of students compared the density of ice with that of water (i.e., they viewed ice as less dense than water). Some based their reasoning on the fact that ice floats in water, while others emphasized the accepted densities of ice and water. Regardless of the nature of reasoning, both groups believed more density meant more mass. Thus they claimed that the mass of water would be greater than that of ice. Another line of reasoning was related to volume change during melting. Some students gave responses like "volume is increased on melting and therefore mass is increased" or "mass of water will be more because volume of water is more than the volume of ice." These students believed larger volume meant more mass, indicating difficulty in differentiating the concepts of mass and volume.

The third line of reasoning was related to the matter, such as the structure of heat. Some students thought heat has mass. Therefore, they expected an increase in mass during melting due to heat being absorbed by the ice cube. When probed further, some explained that heat is energy that is added to the mass of ice. Some, on the other hand, claimed that heat has mass but could not provide further reasoning. The other reasoning of this group was particulate in nature. As can be seen from Table 2, some students believed water molecules to be more energetic than those of ice. This reasoning is familiar, since some students who predicted that mass would decrease during melting predicted such. However, this time the relationship between movement and mass is reversed. Students of this group believed that water molecules move faster, bump into the container, and therefore weigh more.

As with other groups, students who did not expect a change in mass during melting backed up their prediction with different reasons. Some provided conceptual reasoning in explaining the conservation of mass, while others appeared to base their reasoning upon perceptual cues, stressing that nothing was added or removed during melting. According to students using reasoning based on the particulate nature of matter, ice and water molecules are the same, so mass would not change. These students provided acceptable explanations concerning the melting process via the particulate model.

Conclusions

The traditional teaching that students experienced was ineffective because, after instruction, the majority of students in this study did not understand the concept of conservation of mass during melting. This finding is in accord with the literature indicating that traditional instruction, during which the teacher transmits knowledge and points out misunderstandings, is not successful (Driver, 1989; Wandersee, Mintzes, & Novak, 1994).

Students can make the same prediction about mass change on melting but for different reasons (e.g., there were seven ways used to justify the mass of the ice being greater than that of the resulting water). Conversely, some students can use the same reason to support different predictions (e.g., the idea that the energy of particles affects/determines the mass of particles seems to be the common reason behind two different predictions).

Regardless of the prediction of the mass change associated with melting, some of the students supported their ideas via observable features of the melting process. Even those who used the concepts of volume attempted to explain it by perceptual aspects, and this finding is not surprising. Melting is a process that involves apparent volume changes. It is highly likely that students who cannot differentiate mass and volume might use perceptually-bounded volume changes to explain their reasoning. This finding is in line with the findings of other research that indicates students' dependency on perceptual features in their reasoning (Andersson, 1990; Bar, 1989; Bar & Galili, 1994; Johnson, 1998; Stavy, 1990), although these references do not speak for the melting process itself.

This study uncovered students' misconceptions regarding changes in mass during melting. Some of these misconceptions are in line with the findings of previous research, even though most of the latter investigated students' preinstructional ideas. For instance, the idea that solids lose mass on melting (Krnel et al., 1998; Osborne & Cosgrove, 1983; Stavy & Stacher, 1985), and that solids are heavier than liquids (Ault et al., 1984; Lee et al., 1993), are two of these. Similarly, the misconceptions that mass is increased when a substance is heated, and that heat has mass/weight, seem supported by previous research findings that also indicate the underlying reasoning behind these misconceptions to be the idea that heat is a substance or that it has the properties of matter (Schmidt, 1997; Thomaz, Valente, Maliquias, & Aritanes, 1995). The misconception that greater density means more mass/weight also seems to be in line with the findings of previous research (Kind, 2004; Mulford, 1996; Schmidt, 1997). The idea that more volume means more mass also seems to have been reported in the literature, albeit in the context of dissolving rather than melting (Çalık & Ayas, 2007; Holding, 1987; Kabapınar, 2001).

At the same time, this research identifies some misconceptions that have not been reported in the literature previously. These comprise the ideas of molecules being less energetic in ice than in water and therefore weighing more or less, the mass of molecules changing in accord with their movement, and ice being closely-packed and having more molecules than water. It should be noted that these misconceptions were not detected in students' written responses, but rather were uncovered during the interviews. Thus, face-to-face interviews that follow up students' written responses, or an interview-about-instances approach (Osborne & Gilbert, 1980), seem to be preferred methods for studying the origins of students' ideas and the reasoning behind them.

This study reinforces the need to recognize the existence of students' ideas prior to teaching. Specifically, while teaching the concept of melting, teachers will raise the issue of the relationship between heat and mass only if they become aware of the existence of the misconception that heat has mass. It is also important for teachers to be aware of the effects of instruction on students' ideas. As the findings of this study indicate, students can make incorrect connections/conclusions about melting and particles that are a result of science instruction. With such knowledge in mind, teachers can take actions or precautions to avoid promoting misconceptions via their teaching. For instance, they might be more careful in presenting the particulate model of matter as a conceptual tool in explaining the melting concept and in observing the interaction between the two.

Being aware of student misconceptions, though, is not in itself adequate for remedying them. Science teachers need to design specific teaching approaches that start from students' existing ideas and develop these towards the accepted ones. For the topic of mass change associated with melting, it is important that the teacher organize teaching activities where students test their mass change predictions, produce their own explanations as to why their predictions might be incorrect or supported, deduce acceptable ways of thinking, and reject the alternative ones. In this respect, the teacher should design teaching activities to illustrate that heat has no mass/weight, that solid substances are not heavier than their liquid counterparts, and that there is not a linear relationship between mass and volume or mass and density. However, the teacher must invite students to carry out activities, to observe, and to interpret the findings of the activities. Only then can they come to understand the phenomenon in a different, but scientifically acceptable, way.

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Readers' Forum

More on Inquiry

I'm enjoying deliberating over Robert Yager's questions about inquiry, the responses to them from readers (which included my response), and Robert's reply that appeared together in the last issue ("Your Questions Answered," 2007), as it is providing me with an opportunity to clarify and further refine my thinking. In what follows, I aim to continue the discussion by sharing my thoughts on the following issues: Confusion surrounding the use of terminology, misinterpretations concerning both the use of different levels of inquiry and reform visions for science education, distinguishing between the 7E learning cycle and inquiry, and differences that might apply to how inquiry is implemented at different stages of education. I then conclude with a question of my own.

The criteria for inquiry. While a dictionary might define inquiry as to ask a question, this criterion is insufficient for defining inquiry in the context of science education, as the essential features of classroom inquiry shown in Table 1 of Yager's reply ("Your Questions Answered," 2007, p. 107) show. I previously shared the idea that to be doing inquiry science, students need to be engaged in answering a question by analyzing information themselves. I tend to take it for granted that if students are analyzing information, they will also be drawing conclusions from their analyses (which includes making connections with scientific knowledge) and be prepared to justify these conclusions, as this is standard practice in science research proper and also good classroom practice. I find this definition of inquiry to be a satisfying one. Note also that it precludes, for example, the retrieval of information from a library from being regarded an inquiry activity, because although students might be answering a question, they are not analyzing information.

The degree of inquiry. I do not find the notion of the degree of inquiry, determined on the basis of how many of the essential features of classroom inquiry provided in Table 1 of Yager's reply ("Your Questions Answered," 2007, p.107) are involved, to be a useful one. For me, students are either doing inquiry (i.e., answering a question by analyzing information themselves) or they are not. So, I suggest we would do well to delete terms like *full inquiry*, *pure inquiry*, and *partial inquiry* from our vocabulary.

Distinguishing between degree of direction and degree of guidance. I previously referred to the literature categorizing inquiry Science activities according to four levels--Level 1, confirmation; Level 2, structured; Level 3, guided; and Level 4, open--according to which of the following are provided to students; the question, the method, and/or the conclusions. This hierarchy can be viewed in terms of the degree, or amount, of direction provided to students, with the movement from Level 1 to 4 corresponding with a movement from more-directed to less-directed inquiry (or, if you like, from teacher-directed to student-directed inquiry, from closed to open inquiry, or from passive to active learning).

However, I think we need to distinguish between such a degree of direction and the degree, or amount, of guidance provided to students. I previously also provided evidence for why unguided, or minimally-guided, instructional approaches can be considered poor pedagogy with novice and intermediate learners having limited prior knowledge. Those references conclude that unguided learning:

- Does not guarantee meaningful learning (i.e., a change in long-term memory).
- May result in incomplete/disorganized knowledge and misconceptions.

- May cause working memory overload, which in turn may prevent novices integrating all information, leading to poorer learning outcomes.
- May lose and frustrate students.

Students need to be able to benefit from the expertise of their teachers, and this is surely why we devote so many resources to making structures like schools accessible to them. What is more, teachers can, and should, provide guidance to students--as opposed to directing them--at all stages of the inquiry process and at all levels of inquiry. For example, even in the case of open inquiry, where students are investigating their own question, the teacher should support them in ensuring that their questions are suitable--even the best--ones, not by telling them what their question should be but by probing with questions that facilitate students refining the questions they plan to investigate. We probably don't actually need words to describe each level of inquiry, but if we do wish to use such, I now therefore think it follows that Level 3 inquiry would be better termed *directed* rather than *guided*. An analogy for unguided learning might be the scenario of a person enrolling for driving lessons only to find that the proposed role of the instructor is to involve little more than pointing him or her in the direction of a car that has been serviced and is ready to use and showing where the keys are kept!

The need for different levels of inquiry. Returning to Table 1 of Yager's reply ("Your Questions Answered," 2007, p. 107), Robert is rightly concerned that we might misuse this table by never moving past the right-hand column of variations. The content of this column represents the transmission model of learning, a model with widely-accepted limitations that has also been overused. However, with respect, I think he is being at least potentially misleading, if not wrong, in advising that the first column of variations is "what we all should strive to attain" ("Your Questions Answered," 2007, p. 107) and wrong in concluding that inquiry "means learners questioning--not teachers doing it for them!"(p.108), because these tend to convey the impression that the only form of valuable inquiry is open inquiry. As Brown, Abell, and Demir (2006) have recently concluded, this open view of inquiry is an incomplete one that is also the overriding constraint to college science faculty members considering inquiry-based approaches, because it can be time-consuming, unstructured, and difficult to implement both with class sizes of 20-200 students and when students lack the required knowledge and skills. I think that many primary and high school teachers likely share this inadequate view of inquiry.

Inquiry can involve students asking their own questions, but it can also include teachers supplying questions for them. In fact, from my experience, a teacher can actually "engineer" a situation to arrive at a point where students are wanting to ask a question that the teacher--or education system, through the syllabus, should I say--has already decided should be answered! I think a curriculum based solely on students answering their own questions would be unsatisfactory. Rather, I think that offering different levels of inquiry, balanced in an appropriate way, is essential during a course of study. Inquiry also need not require the hands-on manipulation of materials, can be done in a large-group lecture situation, and can even be done using data supplied by the teacher. For example, an investigation into whale migration patterns does not need to require classes around the world traveling to the ocean, catching a whale, fitting it with a transmitter, and then monitoring its movements, because such an inquiry can be readily accomplished using data available on the World Wide Web. The secret, then, is in striking an appropriate balance between all levels of inquiry, and in this way inquiry can best contribute to promoting an understanding of scientific concepts and the nature of science and developing inquiry skills.

Finally, I think Yager ("Your Questions Answered," 2007) errs in viewing Level 2 or 3 inquiry as needing to represent the transmission model of learning. My experience is that both can offer ample scope for student curiosity and minds-on learning as students design investigative methodologies, analyse data, and/or strive to draw conclusions and justify them. One of my favourite approaches is to begin an investigation at Level 3 (i.e., with students designing a methodology to answer a supplied question), but guiding students in such a way that the deficiencies in their designs become exposed and they end up adopting the procedure that I had in mind from the beginning and for which the required materials are available. In effect, a Level 2 activity is being disguised as a Level 3 one. At the same time, novel approaches suggested by students that are readily implemented can, and indeed should, also be accommodated, and possibly by a subsection of a class only.

Reform visions for science education. I think Robert Yager's reply in "Your Questions Answered" (2007) tends to convey a misinterpretation of Table 2 (p. 109), a table that presents reform visions for teaching. The "more emphasis" column is not intended to represent "recommended teaching features" (p. 107), but rather features that are in need of greater emphasis. Again, balance is the key, with the features in the "less emphasis" column still having a place in sound science teaching. There is still a role, at times, for responding to the group as a whole, demonstration, recitation of acquired knowledge, working alone, and so on. Tables 3 and 4 (pp. 110 & 111), that present reform visions for professional development and assessment, respectively, need to be interpreted similarly.

Distinguishing between the 7E learning cycle and inquiry. The 7E learning cycle, comprising the elements of elicit, engage, explore, explain, elaborate, evaluate, and extend, should not be confused with inquiry. The former involves much more than inquiry, which is basically restricted to the explore and explain elements of the learning cycle only. I disagree with Yager that "such lists . . . do not invite thinking and trial, but rather represent recipes for people to follow with little or no thought. They make it easy for students to follow the science processes with no real effort or personal thinking or reason" ("Your Questions Answered," 2007, p. 105). The 7E learning cycle is a planning tool for teachers, not students, and finding or creating activities to use in the design of learning cycles is a very creative, and demanding, pursuit. And I have already mentioned how engaging students can find Level 2 and 3 inquiry. In fact, just like in science proper, surely a primary goal for science education research is to strive to develop learning theories, which may include models like the learning cycle, to guide sound teaching?

Inquiry at different stages of education. I'd like to share a conclusion I have reached--or, should I say, feel myself reaching--on the basis of particularly my personal experience in having guided, over a considerable number of years, Year 12 high school students as they completed individual, open inquiry, hands-on, experimental projects as a part of their Physics course. In asking myself what they gained from this experience that they would not have been able to gain otherwise during the course, the only thing I have identified is that they had been provided with the opportunity to investigate their own question. However, the price to be paid for providing such an experience for students at this stage of education can be high both in terms of staff time and demands on the budget, as somewhat specialized equipment not commonly found in schools can be required to investigate the questions that interest these students, and I find myself having difficulty justifying this effort being made for such students. Scully (2005) has expressed similar sentiments in an earlier issue of this journal, and notably in the less-demanding context of lower-level inquiry in which all students were using identical materials. The growing trend of experimental work that involves simulations and computer modeling can make life here easier, but I find myself doubting the value of forcing every upper high school student to perform a hands-on, experimental, open inquiry during each of their science courses. Rather, I'm thinking that we might do better to encourage students so inclined to undertake open inquiry as an option by, for example, joining the school Science Club. As Vondracek (2007) notes, “often it is not the straight-A student who does the best research, but the kid who can’t stop asking questions or who can’t stop tinkering with the demos and equipment we have in our classrooms” (p. 436), and an option like a Science Club would ensure that we don’t restrict opportunities for those students so motivated to satisfy their curiosity and to “shine.”

However, as Robert Yager advocates (“Your Questions Answered,” 2007), the experience of open inquiry certainly does have a place in science education, but I’m inclined to think that this place might be at the primary and middle school levels--the compulsory years of education, if you like--only, where the benefits of engaging in one or more Level 4, open inquiry experiences can be had particularly without the need for somewhat special materials that are not typically available. This thinking appears to be in accord with the situation in universities, where hands-on, experimental, open inquiry in science courses is generally not a priority, with even postgraduate researchers typically operating at Level 2 or 3 inquiry. In other words, how inquiry is implemented might “look different” at different stages of education, and this is not an issue I have seen addressed in the literature to date. Mind you, facilitating open inquiry at any level is a demanding task, especially given the conditions under which many teachers need to operate. I imagine nobody would consider asking an individual university faculty member to supervise up to 150-odd postgraduate research projects, and yet this is effectively what teachers are being asked to do--and within working structures that were designed for a chalk-and-talk model of teaching! The restriction of open inquiry to middle school and below might remove some unnecessary stress on high school teachers? During the past year or so, I have shared this thinking with participants at some of the teacher workshops I have conducted and am yet to find a teacher who has disagreed, and this is giving me increased confidence that the idea may have some validity.

A question. I have a physical science background. When I think of inquiry, I have in mind the picture of students analyzing experimental data that either they have collected or that has been provided for them, and it is from this perspective that I have written the foregoing. However, I’m also now thinking that such a perspective may be limited. In recognizing that an experiment, which involves the control of variables, is only one type of what can be more generally called a scientific investigation (Schwartz, 2007), I’m wondering how my views about inquiry might change as a result of being shown examples of students engaged in investigations in the broader sense. I look forward to what others may have to say on this issue, or anything else I have written.

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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!

Life Outside Teaching

How do I find time for a life outside teaching? (Editor: Or, put another way, perhaps, what strategies are useful for ensuring a teacher leads a balanced lifestyle?)

I don't know of any scheme to ensure a life outside of one's work as a teacher, but it is perhaps worth noting that if adults are finding the work all-consuming, what does that suggest about the students? If we are having trouble leading a balanced life, wouldn't it seem likely that they are having an even greater problem? I have tended to focus on making class a rich experience and to "de-emphasize" homework. We all need time to simply be people and "smell the flowers," as it were. That tends to mean I am spending more time thinking about class and so are they.

Lou Rosenblatt, USA

About 6 months after beginning to teach, I realised I wasn't keeping such a good balance. I realized I needed a hobby, and my criterion was that everyone needs something they find so interesting that they don't notice the time pass. For me, that was Dungeons and Dragons, and I've lived happily ever since, give or take. That's my medicine; find something so interesting you lose track of time and spend a little time on it every week. It'll do you good.

Joe Ireland, Queensland, Australia

Being a science teacher can be a quite difficult task, and many things will be affected so much. Married teachers will find it hard to balance their work and family if they do not know how to manage. However, since a science teacher is systematic, dedicated, time-bounded, and realistic, life for him or her can be made easy.

One way to achieve this is to have a time schedule. Second, make priorities in your life. Do teaching work on weekdays and make the eve and weekends family time. Give time for relaxation with the family on a Sunday after church. Saturday shall be spent on household work. If you follow this routine, then your life is more meaningful.

Andrea T. Flores, Negros Oriental State University, Philippines

Long ago I came to the realisation that teaching is just a job; it is not your life and I stressed this to all of my staff. I set time limits on when I would do work related to school. From Monday to Friday I arrived early at school and worked later and took as little as possible home. It meant that I had to use my time more efficiently. Less time talking in the staffroom, but not no time, and more time being productive. Weekends belonged to my family. The only time work came home on a weekend was at exam time. I developed hobbies and joined a club. Friday nights was club night unless there was a family activity that took precedence.

Many times I felt guilty walking out of an afternoon with nothing in my hands as fellow teachers struggled under piles of books, but I knew that I was almost up-to-date with my work. Years ago, a principal told me to only ever handle a piece of paper once. From then on, the moment paperwork came in I dealt with it immediately, knowing that if I put it to one side it would soon be buried and forgotten.

Now, on the verge of retirement, I have reduced the stress levels by putting teaching in perspective. It is a job that I put myself into 100% from the time I arrive to the time I leave. Priorities are providing the best teaching possible to my students and supporting my fellow staff. School politics and all that go with it are not important and are ignored.

Kerry Barnes, Windaroo Valley State High School, Queensland, Australia

This is a difficult question, but one that needs addressing. In my opinion, if you are going to be a good teacher, you have to be an interesting person (i.e., one who does other things except teach!). One trick that helped me a while back was to sign up and pay for evening classes. This meant, because I had paid for them, that I felt obliged to attend. Only one evening a week, but it made all the difference. Sometimes it made the following day's lessons not as well planned as they might have been, but one evening a week for something other than planning/marking was brilliant. It’s also nice to be on the other side of the desk for a change.

Another idea, to make more time for yourself, is not to do everything yourself. Let students mark their, or each others, homework sometimes. This frees you up some time, but is actually also good practice for the students and helps them to see what is needed. OK, you can scan check it afterwards if you are worried about how students have marked, but this takes less time. Also, you could try to set some pieces of homework that don't require marking, such as learning (for a short test that will be marked in class), reading (oral test in class), or researching.

Then just be very, very organized. Save your planning notes, worksheets, etc. for next year. Learn to say “no” sometimes if you are asked to do extra. Make use of any lesson plans already in existence--don't reinvent the wheel. Use IT to your advantage where it saves time (e.g., spreadsheets for converting marks to grades).

Sue Howarth, Tettenhall College, UK

Coach your personal life like you do your profession. Reading your question led me to think that you invest a lot of time in your teaching and, as a professional teacher, I guess you use planning strategies. I suggest you use the same strategies that you use as a teacher to control your own life.

Before entering a class, teachers have planned their teaching. They think about goals for each lesson and for the semester, plan how to achieve these goals, and determine criteria that will help them to know whether the goals have been achieved. If you want to use this strategy in your private life, first try to identify personal goals. These can be things like achieving a higher academic degree, finding love, and engaging in a personal hobby, and can also be connected to your family. After you find the most important goals for you, plan how to achieve them. For example, if you wish to have a higher academic degree, find out about the registration, conditions, and payment. Then, check with yourself what you should do in order to be able to insert your new activity into your schedule. You might want to teach less hours next year in order to be able to carry out your plan, you might need to have help at home (if you have children), and so on. The next stage is to make all the arrangements necessary to allow your goals to become a reality, such as talking with your principal and asking for a less crowded schedule or finding a good babysitter.

I believe this is a good strategy that can help you control your life and better organize your time. Choosing your most important goals and achieving them is an excellent way to put meaning into your life.

Ron Blonder, Israel

There is always a temptation to treat any profession as either merely a path to a salary or conversely as a mission. An answer to the dilemma of work-life balance can be found, I believe, in our conceptualisation of the job itself.

Teaching is a profession and teachers, in most jurisdictions, must be registered after proving their credentials. Therefore, after a period of probation and the garnering of some experience, teachers should be trusted to make informed decisions about what to teach, when to teach it, how to teach it, and what physical and social environment to build (or help students build). The job of the teacher is to make professional decisions based on evidence. We need to think of parallels with dentists and architects rather than Mother Theresa or Albert Schweitzer.

If we look at our profession in this light, it becomes much easier to place limits on our commitment of both time and energy. We have a valuable and valued role to fill, but we cannot save the world. The physical and emotional labour inherent in teaching school students can be extremely draining. Personally, I keep track of my professional commitment by logging my time each day and each week. I am quite prepared to commit 50+ hours to a job I value and enjoy, but if the hours start drifting towards 60 I know that this will have effects on my family, my well-being, and eventually the quality of my professional performance.

Allan Thomas, Queensland, Australia

Teaching is tough, but there can be life outside teaching by carefully planning, organizing, and setting life priorities to be balanced. It is a matter of perspective; life is more than having a career. First, the teacher must see herself as a total human being who has a body, soul, and mind to take care of. If any of these is out of proportion, it will affect her effectiveness as a teacher. Therefore, the teacher must budget time weekly to include activities to take care of her body, soul, and mind. Share the plan with a trusted friend or colleague who can hold her accountable by constantly reminding her of her plans and perhaps commend or rebuke her when she follows or deviates from her plan. She should cultivate such a friend if she doesn't have one, and this friend could be a spouse or her grown-up child. For example, the following can give a balanced face to life: Join a book club, read the Bible or some religious books, visit at least one friend or relation (or a widow/widower/orphanage/prisoner) each week, take a walk/another preferred sport/exercise, relax over a cup of tea/coffee while watching a movie or news, go shopping, and take a nap.

Secondly, learn to leave school work at school most of the time so that when you are home, you do home things--relating to people, relaxing with people, empathizing with people, celebrating with people, and so on. Both my husband and I hold PhD degrees and have tried this over the years. It works because you feel refreshed back in school when you learn to budget and give time to the various facets of your life relationships, of which teaching is only one. Finally, learn to say no to some assignments that the school may want to load on you, especially if there are other colleagues who can do the same thing. This requires discipline.

Elizabeth Gyuse, Benue State University, Makurdi, Nigeria

Over the years, I've heard or read several varying versions of the following story. An expert on time management was speaking to a group of students. To drive home a point, he used an illustration those students will never forget. As he stood in front of the group of high-powered over-achievers, he said: "Okay, time for a quiz." Then he pulled out a large, wide-mouthed jar and set it on a table in front of the group. He placed fist-sized rocks carefully into the jar, one at a time, until no more would fit inside. He asked: "Is this jar full?" Everyone in the class said "yes."

He reached under the table and pulled out a bucket of gravel. He dumped gravel into the jar and shook it around, causing pieces of gravel to work down into the spaces between the big rocks. The man smiled and again asked the group: "Is the jar full?" By this time, the class was onto him. "Probably not," one of them answered. "Good!" he replied.

Then he reached under the table and brought out a bucket of sand. He began dumping the sand in and it went into all the spaces left between the rocks and the gravel. Once more the man asked the question: "Is the jar full? "No!" the class shouted. Once again the man said "good!"

Next, the man grabbed a pitcher of water and began to pour it in until the jar was filled to the brim. He looked at the class and asked: "What is the point of this illustration?" One eager student raised her hand and said: "The point is, no matter how full your schedule is, if you try really hard, you can always fit some more things into it." "No," the speaker replied, “that's not the point. The truth this illustration teaches us is: If you don't put the big rocks in first, you'll never get them in at all."

As teachers, we each need to determine the "Big Rocks" in our lives--personal health and wellness, family, spiritual and social connections, and so forth--and fit them in first. Personally, I find that if I get up early and go for a run, that time is my opportunity to connect with my spiritual side, reflect, sort, prioritize, enjoy nature, and daydream. After spending that time on myself, I am more willing to let external demands have the rest of me, whether it be my family or my work world.

A lot of emphasis is put on finding balance in our daily lives. Sometimes that notion is stressful in itself, imparting a sense that we are somehow not living up to a reasonable expectation if we don't pile on exercise, quality time with family, journaling, meditating, etc, etc. I've learned over the decades to look at balance in my life over a larger time span. I've had eras where the major focus has been child-raising, eras of my primary focus being on my teaching skills, eras of extending my education, and even eras of serious running and marathons. But not all at the same time!

There's another mind game I encourage my over-achieving pre-service teachers to utilize. If your major focus is on being the best teacher you can be, realize you'll be an even better teacher if you are physically fit, mentally healthy, have social diversions, variety of experiences, and so on.

Lynne Houtz, Creighton University, Omaha, NE, USA

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.

#4 of 40. *Encourage Caring About One's Health and Safety*

Employees, faculty, staff, and students need to be encouraged to develop a genuine concern about their own health and safety. It's too easy to care less and become careless. One of the most important ways to do this is through education into the nature and seriousness of particular hazards and their potential consequences. I read of a hypothetical case where someone placed a rattlesnake in someone else's mailbox. If asked if it was dangerous to reach into his mailbox, the owner would say "of course not." Others who knew about the presence of the snake might think differently.

A good way to make your point is through the use of examples where others have in fact been seriously injured or killed doing exactly the same activity. This is why it's so very important for us to share our knowledge of these experiences. LSI publishes a series of books titled *Learning by Accident* based on our collection of more than 5,000 accounts of laboratory accidents. Each volume in the series contains 500 anecdotal accounts, and Volumes 1, 2, and 3 are currently available. The most serious accidents (over 300) have been compiled in a separate LSI publication, *85 Years of Progress*.

Another good way to encourage others to care about their health and safety is to enforce the rules. If EH&S is going to be truly important in your organization, the rules need to be enforced. Otherwise, they are just lip service.

As a final example of a way to get others to care, lead by example. People pay one hundred times more attention to what you do than to what you say. Set the gold standard. Be the poster child for best safety practices. As a teacher or supervisor, when you show a genuine concern for the health and safety of those that you supervise or teach, it encourages the development of their own concern. My first supervisor at Dow, Don Dix, was particularly effective in this respect and that contributed significantly to increasing my concern and interest in health and safety.

What do you do to show your concern? Let us at LSI know so we can share your success with others.

Further Useful Resources

MedMyst: Medical Mysteries on the Web (http://medmyst.rice.edu/index.html) Students of all ages may play the role of scientists, historians, and detectives as they help solve medical mysteries in infectious diseases in a futuristic world. The problem-based, interactive learning adventures facilitate understanding about how infectious diseases are spread.

Student Independent Science Research
(http://facweb.eths.k12.il.us/chemphys/science_research_papers.htm) Information about computational research and other aspects of student research.

Science and Religion in Schools (http://www.srsp.net) A project that provides teacher resources, in the form of a guide and CD-ROM for each of primary (7-11 years) and secondary (11-19 years) schools, seeking to encourage open-minded and informed debate on the claims of science and those of the major world religions.

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