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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

The World's Most Deadly Poison

Depending upon how you choose to define "most deadly," the world's most deadly poison could be either tobacco or botulin toxin, which is produced by botulinum bacteria and associated with botulism, the most severe form of food poisoning. If you are referring to the substance responsible for the most deaths each year, tobacco is a very clear "winner," with 4.5 million people worldwide dying each year of tobacco-related illnesses. However, if you are referring to the smallest dose (mass) required to cause death, botulin toxin can make claim to being the world's most deadly poison.

And now for the interesting (or should I say scary?) part. When you receive BOTOX injections, very dilute solutions of botulin toxin are used to paralyse facial muscles and remove the wrinkles!

Source: Becker, B. (2004). Questions from the classroom. *ChemMatters*, *22*(4), 2.

Science Story

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

A Noble Experiment

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During the Second World War, the invading armies of Nazi Germany were known for looting treasures from the countries they occupied. Countless paintings, tapestries, sculptures, and assorted valuables were stolen from countries such as France and Belgium, and returned to Germany as the "spoils of war."

George de Hevesy was a Nobel prize-winning Hungarian chemist who lived in Denmark in the 1940's, when the German army invaded the country. Afraid that their golden Nobel prize medals would be stolen by the Nazis, two famous chemists approached Hevesy asking for help in hiding them. The Nobel prize medal is made of 200 grams of solid gold, worth about 3,000 USD at today's prices. And they came to the right place. Hevesy had done ground-breaking work on dissolving unreactive metals, such as copper, in strong acids. Using a mixture of nitric and hydrochloric acids, he prepared a substance called *aqua regia*, so strong that it was able to dissolve the gold medals into a colourless solution.

When the Nazis came, all they found was a scary-looking bottle of acid on the dusty old shelf. They left empty-handed. After the war, by adding chemicals to the solution, Hevesy was able to precipitate out the gold and the Nobel prize foundation melted it down and re-moulded the medals for the two chemists. They had their medals back, and the Nazi's had been duped by clever chemistry!

Design-Based Science

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Abstract

Design-Based Science (DBS) is a pedagogy in which the goal of designing an artifact contextualizes all curricular activities. Design is viewed as a vehicle through which scientific knowledge can be constructed. DBS units are structured around a learning cycle based on models of design and a socio-constructivist perspective of learning.

We are born designers. When children think about ways to connect a wagon to a tricycle in order to pull their friends behind them, they are designing. When you consider how to organize your desk so that everything you need will be easily accessible, you are designing. We all purposefully use tools and materials in adapting our surroundings to suit our needs. Design-Based Science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004) is a science pedagogy that aims to help students construct scientific understanding by building on this natural and intuitive experience with design. The design of artefacts in DBS is not viewed as a culminating experience, where the students attempt to apply scientific knowledge, constructed in the traditional manner of focusing on well-defined problems, to a real-world problem. Rather, the design experiences lie at the heart of DBS. All scientific knowledge is constructed in the context of designing artifacts.

The Design Process

Everyday design is not the same activity as Design (capital D) in which professional designers engage. The two differ in their level of formalization: while everyday design is usually spontaneous and intuitive, Design usually includes many explicit stages and criteria for determining whether the outcomes of the Design process are acceptable. Everyday designers often err in their decisions and considerations, whereas the Design process attempts to minimize the chances that Designers will do so as well. The Design process has much in common with scientific inquiry, as demonstrated in Table 1.

It is often difficult to engage students, especially younger students, in authentic scientific inquiry. By authentic, I mean that the classroom activities are both good simulations of scientific inquiry as experienced by professional scientists and something that the students can relate to on an intuitive level. However, by engaging students in Design, DBS does just that. Students can gain experience in DBS contexts that will support their forays into scientific inquiry, because they will already be knowledgeable and well-acquainted with many of the aspects of scientific inquiry.

Table 1
Commonalities Between the Design Process and Scientific Inquiry

Design process	NSES[a] inquiry standards
Identify and define the problem	Pose questions
Gather and analyze information	Review what is already known
Determine performance criteria for successful solutions	Make predictions
Generate alternative solutions and build prototypes	Plan investigations Consider alternative explanations
Implement choices	Make observations Gather, analyze, and interpret data
Evaluate outcomes	Propose answers and explanations Communicate results

[a]National Research Council (1996).

As examples of the DBS pedagogy, consider three ninth-grade units that were developed at the University of Michigan. All three units are standards-based (National Research Council, 1996) and structured around design problems chosen to be interesting and challenging to the students. In the first of these DBS units, called “How do I Design a Structure for Extreme Environments?” the goal is to design and build a model house that can withstand extreme environmental conditions. In the second unit, “How do I Design a Battery That is Better for the Environment?” the goal is to design and build a wet cell that makes use of nontoxic materials. In the third unit, “How do I Design a Cellular Phone That is Safer to Use?” the goal is to design a cellular phone that minimizes potential radiation and sound hazards without compromising customer appeal. Each unit begins with the presentation of a design specification that includes the requirements the students’ models are expected to fulfill. Please see Appendix A for an example. Thus, the students know in advance what the unit is about and what is expected of them.

A Design Learning Cycle

Since the goal of DBS is not to foster learning about Design, but to use Design as a vehicle for learning science, it is necessary to provide a scaffold that allows the students to engage in Design without needing to explicitly instruct them on the Design process. This is achieved by organizing each DBS unit around multiple applications of the learning cycle shown in Figure 1.

The structure of the learning cycle is based on a stepwise description of the Design process and a social constructivist perspective of learning. In order to acquaint the students with the stages in the Design process, each cycle is usually completed in an orderly manner. However, as is to be expected for a nonlinear process, there are cases that short-circuit steps in the cycle, or have steps executed out of order.

Each cycle, in each of these DBS units, focuses on a different aspect of the unit’s design problem. The “How do I Design a Structure for Extreme Environments?” unit is composed of five cycles, dealing with weather conditions, technical drawings, different sources of loads, shape and structural integrity, and thermal insulation. The “How do I Design a Battery that is Better for the Environment?” unit is composed of four cycles, dealing with toxic materials and their disposal, different types of batteries, the materials from which they are made, and the health hazards related to these materials, how batteries decay and how to measure this, and electrochemistry. The “How do I Design a Cellular Phone that is Safer to Use?” unit is composed of five cycles, dealing with the potential hazards of EM radiation, the historic form and function development in telephones, general wave characteristics, sound waves, and EM waves.

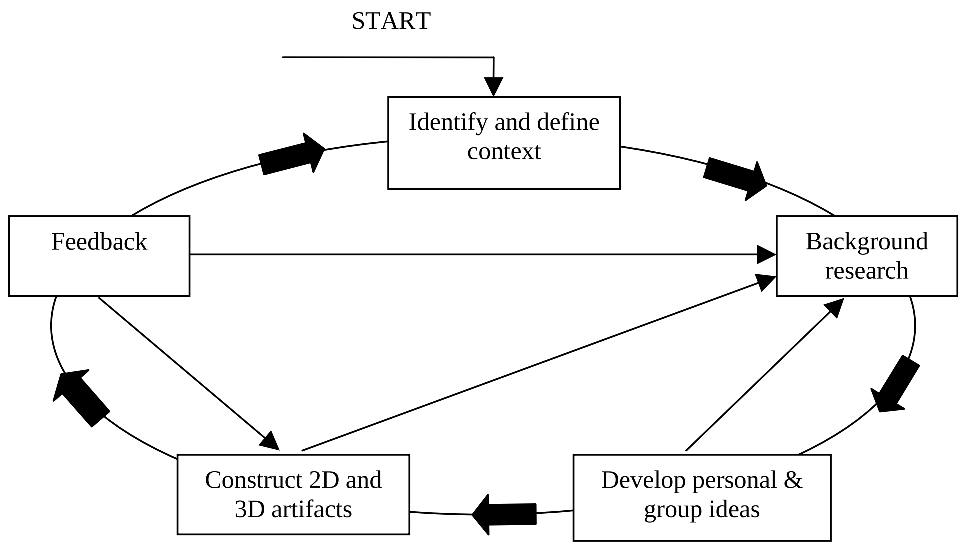

Figure 1. The Design-Based Science learning cycle.

In each cycle, students conceive, design, construct, and modify models of structures for extreme environments, batteries that make use of safe materials, or cell phones that pose less of a potential hazard to their users. During the unit enactments, a poster of the learning cycle is displayed on the wall at the front of the classroom. The learning cycle is presented briefly to the students near the start of the first cycle of each unit, and then it is mentioned at the start of each lesson, with the teacher pointing out how the day's planned activities fit in the cycle.

Steps of the Learning Cycle

I now elaborate on the various steps in each learning cycle, giving examples drawn from the Extreme Structures unit.

Step 1: Identify and define context. Each cycle begins by setting the context for the cycle's focus. Context supplies significance for the tasks the students will be facing and provides starting points for things the students can immediately begin to investigate. For instance, the first cycle in the Extreme Structures unit begins by showing the students films depicting an arctic blizzard and a Sahara sandstorm. This leads directly to a research activity in which the students inquire into the weather conditions (temperature, precipitation, and wind speed) typical of these two different extreme environments. It is important to grapple with a subject in more than one context. By teaching a subject in multiple contexts, there is a greater chance that students will succeed in constructing a more flexible knowledge representation and enhanced ability to apply the knowledge in new contexts. DBS units present each concept in at least two different contexts. As another example, thermal insulation is discussed in the context of a house, an ice cube in a tin can, and a cup of hot chocolate.

Step 2: Background research. Background research can be in the form of benchmark lessons that include the teacher presenting new scientific concepts, the reading of selected materials, searching and gathering relevant information, the sharing on a whiteboard of data collected in group experiments and then collectively analyzing the complete database, teacher-led demonstrations, computer-based simulations of relevant phenomena, and a virtual expedition to examine appropriate primary sources.

As an example, working in groups of four in a jigsaw activity, students in the Extreme Structures unit investigate the dependency of a beam's vertical deflection on the mass of a weight being hung from its center and on the distance between the beam's two support points. Each group is given a yardstick (beam), which they support between two tables (pillars), and every group places their tables at a different distance apart (different spans). They then hang a series of weights from the center of the yardstick, measure the yardstick's vertical deflection for each weight, and create a graph of the yardstick's deflection against hung mass. The teacher prepares a table on the whiteboard, with each row representing a different span and each column a different mass. The cells in the table represent the various vertical deflections. A representative from each group fills out the cells in a particular row according to the group's measurements. The teacher also prepares a blank graph with axes representing deflection and hung mass. Using different colored markers, representatives from each group draw a different deflection versus mass curve. After discussing the results, explaining how span is a varying parameter in this graph, and clarifying any misunderstandings, the teacher shows how the same results can be graphed differently as span versus hung mass, with deflection as the varying parameter. Thus, for a known mass, students can select the span that will give a desired deflection. The teacher explains that this is how an architect would approach the problem and how they can use what they've learned in the investigation in designing their structures; that is, by knowing the mass a beam has to support and knowing the maximum vertical deflection the beam (roof) can tolerate, you can determine the maximum distance between the pillars supporting the beam.

Step 3: Develop personal and group ideas. Activities are carried out on four levels: individual, pairs, groups of four, and the entire class. Following the background research stage, every student comes up with his or her own design solution, be it a method to prevent the roof of a structure from sagging, or a scheme for increasing the thermal insulation of a structure. Group problem solving that involves open-exchange and elaborate discussion among group members can enhance student learning. Thus, the students present their solutions to their group members and the group decides which of the four suggested solutions they prefer, or perhaps they decide to combine the solutions in some manner, and they write a justification for their decision. By providing an opportunity for the students to contrast their own thinking with that of others, the students begin to develop a critical appreciation of the different aspects of the problem that will assist them in learning new and related information.

Step 4: Construct 2D and 3D artifacts. In the next stage, each design team splits into pairs, with each pair constructing a model, or modifying an existing model, based upon the design solution their design team decided on in the former stage. The construction work is done in pairs, rather than in teams, in order to provide each student with as much hands-on interaction as possible with the various aspects of their models. This is the stage when the students' ideas are concretized. Concepts and notions that may have been vague and unspecific need to be reevaluated and reorganized in order to allow them to guide the development of a material artifact. The students realize the appropriateness and reasonableness of some of their ideas, and the unsuitability and impracticality of others, opening the way for some conceptual models to become entrenched and others to be replaced.

After each pair has constructed or modified a model, they rejoin their design team members to discuss and compare their models. They decide which model is superior and then prepare a document to justify it. The justification is based on the document they wrote in their design teams in the former stage and the experience they gained while constructing, modifying, and comparing their model.

Since every team is divided into two pairs, and each pair builds a model according to a solution agreed upon by the entire design team, the two models built by the two pairs should bear a great resemblance. However, since the students' ideas and understandings are themselves modified while constructing the physical models, there is also some variance between the two models. Close inspection and analysis of these models can provide the teacher a window to the students' understandings. This inspection is carried out in the next step.

Step 5: Feedback. Ongoing formative assessment provides students with opportunities to revise and improve their understanding, thus supporting their learning. Therefore, students' models are subjected to physical tests whenever possible, and they are presented several times to the entire class in a pin-up session in which the models are laid out or hung up and the entire class moves from model to model, listening to the student-designers' descriptions and the teacher's comments, and offering their own critique.

Not every model built is assessed. Every design team builds two models and decides which one they think is superior. In order to maintain a reasonable limit to the time spent on the feedback sessions, only the select models are critiqued or tested. When subjecting their model houses to physical tests, such as determining whether they provide sufficient thermal insulation, the students are not only testing their models to see whether they meet the specification requirements, but they are also learning about testing procedures in general. They learn how the physical characteristic being evaluated determines what type of data needs to be measured, what other characteristics need to be controlled, how to organize, and how to analyze the data. Likewise, while receiving and giving feedback in a pin-up session, they are not only learning about the pluses and minuses of their own model, but learning how to present their ideas clearly and simply so that others may understand. They are also learning from the comments given to their peers' models, which may reveal ideas that they didn't think of.

Enactments and Outcomes

All three units were enacted in three classes in the sole high school of a small industrial town located near Detroit, Michigan. All 92 students who participated in the enactments came from blue-collar families, and many were entitled to free or reduced-price lunch. During the enactment, there was a 16% turnover in the student population. The teacher had 3 years experience teaching, but only one term of doing any inquiry-based instruction.

The students' understanding of the science content in each unit was assessed by identical pre- and post-tests. There were three different tests, one for each unit. The tests comprised multiple-choice and open-ended items that probed for different levels of understanding using low, medium, and high-cognitive-demand items. The tests focused on the specific science content that was addressed in each unit, in contexts similar to those used in each unit. Although it was originally intended to use the tests only for research purposes, the teacher chose to use them as the final exam for each unit. The results are shown in Table 2.

High and low achievers were defined as those students who scored above and below the median in a pre-test, respectively. The mean gains for both groups were calculated. The results show that learning gains occurred for both high and low achievers. Other analyses showed that there were probably ceiling effects that limited the gains of the high achievers. The effect size is the ratio of the mean gain to the standard deviation. An effect size greater than 0.8 is generally considered to indicate that significant learning occurred.

Table 2
Pre- and Post-Test Results

Unit	Pre-test median	Mean gain		Effect size
		Low achievers	High achievers	
Structures	7.9/23	8.3	5.3	2.1
Batteries	6.7/22	6.4	3.7	1.9
Cellphones	3.0/21	8.0	6.4	2.7

Student learning was also assessed through artifact analysis. Figure 2 shows a model structure built by a group of students toward the end of the Extreme Structures unit.

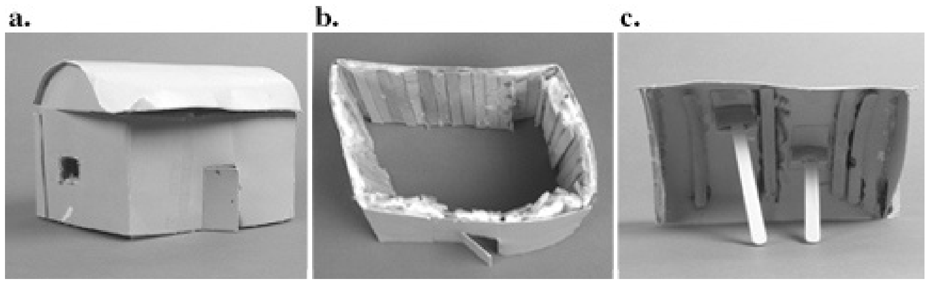

Figure 2. An example of an Extreme Structures model. Part a shows the complete model, part b the construction of the walls, and part c the construction of the roof and its supports.

The model is made of construction paper, Popsicle sticks, and cotton. The structure is a parallelepiped, with an arched roof to keep snow and sand from piling on it (reasoning given by the students). Initially, the students used only four bent beams to support the roof, but when weights were placed on the model, the roof started to cave in (the beams did not lie on top of the vertical walls), so rather than adding other horizontal beams that would be perpendicular to those shown, they added two pillars near the center of the structure. The walls are made of vertically placed Popsicle sticks and construction paper, with cotton between them as thermal insulation. When placed inside an ice chest for 1 hour, the air temperature inside the structure decreased by only 3ºC, even though the initial temperature difference between the air inside and outside the structure was almost 20°C. Why the sticks were placed on the inside rather than the outside is unclear. The window and door were placed on different walls to allow a breeze through the structure. The door can open only outwards, so it remains stuck when there is snow or sand piled on the ground. There is no floor, nor is there a description of how the structure would be held in place. The students stated that the outside walls should be painted either white or black, depending whether the user wanted to reflect light (desert conditions) or absorb it (arctic conditions).

Caveat

Like every science pedagogy, DBS too has its drawbacks:

A. There is a multitude of design solutions that can meet any given specification; some may be better and some worse, but many can be acceptable responses. It is difficult for the teacher to know in advance what form the design solution of a group will take. The existence of this multitude of “correct” responses may make it difficult for many teachers to use DBS units, as it requires them to relinquish their traditional role of knowledge imparters.

B. Design is not a convenient context for learning about the microscopic world.

C. In some sense, the design specification in DBS can be viewed as setting up a competition in which the students compete, not with each other, but with the specification. A design goal like “Can you design a cellphone that is safer to use?” sets a challenge, daring the students to test their skills and knowledge and see if they can design a cellphone that fulfills all of the specification’s requirements. Like ownership, a sense of challenge can be a powerful motivator. However, it can also deter some students.

Part of this article is a summary of Fortus et al. (2004). The author would like to thank John Wiley & Sons for permission to re-use some material. The Fortus et al. study was funded in part by the US Department of Education as part of Technology Challenge Grant R303A960188-99. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author, and do not necessarily reflect the views of the US Department of Education.

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Appendix A

Structures Project

Extreme Structure Design Specifications

Learning Set One: Introducing the Driving Question

The continuing quest for oil, the effort necessary to study a new species, or the desire to be the first explorer in an unknown terrain are causing scientists to venture into environments that are more extreme than what we experience everyday. Research is being done in the deserts of Africa and among the plains of Antarctica. Under normal conditions, researchers can work in these environments. However, under extreme conditions like blizzards or sandstorms, these environments become too hostile for unsheltered human survival.

You goal is to design and build a model of a structure that can provide protection in the harsh weather conditions of different extreme environments.

The requirements for the survival structure are that it:

- ✓ must function in two extreme environmental conditions: arctic blizzards and desert sandstorms.
- ✓ needs to withstand the static and dynamic forces caused by the climatic conditions of the environment it is in. **Antarctica** has high winds that carry snow and the **Desert** has high winds with sand.
- ✓ needs to maintain an internal temperature between 0°C and 30°C for at least 1 hour, without internal heating or cooling, even though it may be subjected to intense sunlight and the temperature outside may be as low as -20°C and as high as 40°C.
- ✓ needs to fit within a space of 5 x 4 x 2.5 meters.
- ✓ needs a door for entry and exit and a window to view the outside.

Each designer will need to do **research** to gather specific facts about the:

- climatic conditions,
- engineering principles behind dead and live forces,
- best aerodynamic shapes for the structures, and
- best way to insulate a structure to maintain a constant temperature.

At the end of the unit, each designer will produce a:

- 1:50 **scale model** of the structure.
- **concept diagram** and **scale drawing** of the structure.
- **written description** of the testing process, and a **written review** of the testing results to support the safety of your structure.

Demonstration

While the activities in this section of *SER* have been designated demonstrations, some might easily be structured as hands-on student learning experiences. Although some sample lesson sequences may be included, the notes provided both here and in the following *Student Experiments* section are meant to act primarily as stimuli for classroom activities and to provide teachers with background information, so please modify any sample pedagogy as you see fit.

The Edible Candle

By: Lynne Houtz, Creighton University, Omaha, NE, USA lhoutz@creighton.edu

On pages 35-36 of this volume of SER, I referred to the use of a discrepant event, such as the Edible Candle demonstration, at the beginning of class as a strategy for gaining immediate student attention. Following is a lesson plan for that demonstration, which requires observation, inference, and the generation of hypotheses.

Safety: Students should not handle the flaming items, nor try to duplicate this activity on their own. The teachers should model safety by using safety glasses. Have water handy.

Needed. Wax candles of varying colors, heights, and textures, large potato, apple corer (or piece of metal pipe), knife, large nut (e.g., a Brazil or almond nut), 10 mL lemon juice, plastic sandwich bag, source of fire (e.g., candle lighter or matches), paper towels, safety glasses, and container of water (for safety).

Advance preparation. Shortly before class, use the apple corer to cut out a cylindrical, candle-shaped section of the potato. Trim the ends of the potato with a knife so it is flat and stands up. Cover the potato "candle" with lemon juice by soaking briefly in the sandwich bag. This prevents oxidation and improves the taste somewhat. Carve a piece of the nut into a "wick," and insert it into the top of the candle. You may need to use the knife to form a slit, in the top of the potato candle, to hold the wick.

Invitation. Just before class starts, line up a set of about six candles and include your potato candle in the lineup. When class is due to start, have students take out a sheet of paper (or make mental notes) of observed similarities and differences between the candles. Put on safety glasses, dim the lights, and light all candles. While lighting, call for students to share their observations. Typical responses include different colors, shapes, heights. Students are also likely to include inferences based on their prior experiences, such as that they are all made of wax, have string wicks, and the like.

While the potato candle, with nut wick, is still burning, pick it up, put it flame first into your mouth, and eat it! Make sure you first have some saliva on your tongue, and exhale to blow out the flame on its way into your mouth.

Exploration. Steer the discussion into the distinction between observation and inference, and the impact of prior knowledge or naïve conceptions. Call on individual students to ask 20 yes-or-no questions to try to determine the real make-up of the candle and wick. Direct students to note the scientific process of narrowing down the options, gathering data, sharing knowledge, and so on. If the class cannot guess in 20 questions, identify what they have determined the candle is NOT.

Concept introduction. Relate the process to the work of scientists. Note that with many scientific hypotheses, there is no instructor to confirm their guesses or ultimately give the correct answer. For example, scientists have not been to distant stars nor had their hypotheses confirmed by "writing on the wall." However, they take what information the science community has gained, rule out some hypotheses, and build new ones. Therefore, if students cannot determine how the candle was constructed, the teacher may choose not to give out the secret. I usually give several opportunities throughout a class period for students to come up with other questions or guesses, until the correct answer is arrived at.

Student Activity

Reminder: Appropriate risk assessment, supervision, and guidance are necessary.

Mining and Conserving our Earth Resources: The "Earth Cake" Activity

By: Lynne Houtz, Creighton University, Omaha, NE, USA lhoutz@creighton.edu

In this hands-on/minds-on activity, students work with partners, or in small cooperative groups, to investigate a model of layers of soil and to model responsible mining and land reclamation.

Safety: The earth cake model contains nuts, flour, chocolate, and other ingredients that may trigger allergic reactions, so students should not taste, or eat, such materials.

Needed. Two 9" x 13" cake pans (recyclable aluminum pans are good), vegetable spray, yellow cake mix and associated ingredients, chocolate cake mix and associated ingredients, 3 cups Brazil (or other) large nuts, small plastic dinosaurs, green frosting for two cakes, plastic plants, cutting and serving utensils, paper plates, mining tools (plastic knives, plastic spoons, and toothpicks), balance, paper towels, and Play Money.

Advance preparation. Prepare the yellow cake mix according to the package directions, pour half the batter into each cake pan (the extra cake that isn't mined and handled may be consumed by the students), sprinkle large nuts over the batter, and place dinosaurs over the nuts. Prepare the chocolate cake mix according to its package directions, pour this chocolate batter over the top, and bake as directed. When cool, frost with green frosting and, after cutting, place plastic plants on top of the slices.

The task. Each group will receive one slice of earth cake on a plate. Also, assign a few students to act as Environmental Protection Agents to inspect the mine sites for proper reclamation.

1. You are a team of miners concerned about conservation. Discuss ways to locate, and mine, the precious minerals (Brazil nuts) with the least damage to the earth.
2. Carefully remove as many precious minerals as possible.
3. Clean the minerals of excess earth materials.
4. Determine and record the mass of your minerals.
5. If your minerals are worth $100 per gram, how much money did your mine make?
6. Reclaim your land so that vegetation is growing in topsoil.
7. Invite the Environmental Protection Agent to inspect your reclaimed land. If topsoil does not cover all subsoil, a fine of up to $500 could be imposed. If vegetation cannot grow on top of the entire mine, the fine could be up to $500.
8. Calculate the profit of your mine. Divide the profit among the mining team members.
9. Successful miners may purchase pieces of cake with their profits, if they choose.
10. Describe anything else of interest that you may have found in your mine.
11. What is different between this experiment and mining in the real world?
12. Why is it important to reclaim the land?
13. What will you tell people you learned today?

Clean-Up

1. Dispose of your earth cake model, minerals, toothpicks, and paper towels.
2. Wash the tableware and put in the proper place.
3. Share the washed dinosaur fossils, as evenly as possible, among your classmates, and keep them.

The Earth Cake mining activity links to the Science/Technology/Society issues of social responsibility and the long-term results of human endeavors. This is timely and relevant, as the search continues today for economical sources of fossil fuels. The serendipitous discovery of the dinosaur “fossils” simulates the nature of accidental scientific discoveries. For more strategies, and modifications of this activity, that improve motivation and success in science learning for students with special needs, see Houtz and Watson (2002).

Using food in the elementary classroom. There are many occasions when elementary teachers might consider using food items as a teaching and learning resource. Candies and other edibles might be used as math manipulatives. Cultural lessons might include traditional foods of a country being studied. Life celebrations and holidays call for cakes and treats. Snacks might be used as rewards, or simply to boost energy or morale. Fruit bowls might be used for still life art activities. Science demonstrations and activities might incorporate foods to be tested, explored, compared, and so forth. Teachers choose to use these food options because they can be highly motivating to children, fun for the teacher as well as the students, easy to obtain, and relatively inexpensive compared to other teaching resources. Before choosing edible items as a tool, though, several factors need to be considered.

1. The use of food may detract from the learning objectives. Students may miss the real point of the lesson.

2. Snacks, treats, and edible manipulatives may contradict the nutrition messages conveyed by teachers or families.
3. Students may have a number of health issues that need to be considered, including life-threatening allergies or diabetes. Orthodontia might limit chewing choices.
4. School districts may have stringent guidelines about food in classrooms, including timing around subsidized lunch programs, or strict restrictions on parties, celebrations, or homemade baked goods.
5. Maintaining sanitation of handled goods can be a challenge and a health issue.
6. Food items can be very distracting to hungry children.
7. A child's religion may have expectations related to food consumption. Fasting or abstinence by devout followers of the Catholic, Jewish, and Muslim faiths need to be respected at certain times. Jews may need the food to be kosher. Jehovah Witnesses may exclude themselves from religious holiday or patriotic celebrations.
8. The burden of these activities falling on the teacher includes the effort and expense of making or purchasing, setting-up, supervising, and cleaning up.
9. If treats are used as a reward for class performance, students may come to expect food as a motivator or reward in the future.

Teachers need to take all the above into consideration before choosing an activity that incorporates food. If the teacher is considerate, and decides that the use of food is appropriate for meeting the selected learning and behavior outcomes, students must still be given the choice to opt out of an activity and never be required to consume an item. And of course, teachers should always document their safety and choice considerations.

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"P.S. - I'm white too": The Legacy of Evolution, Creationism, and Racism in the United States

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Abstract

Despite decades of science education reform, creationism remains very popular in the United States. Although neither creationism nor evolution is inherently racist, creationists and evolutionists have used science to justify white supremacy. Powerful racist organizations such as the Ku Klux Klan and popular racist advocates such as Frank Norris worked together to vilify evolution, promote racism, and begin the evolution-creationism controversy in the United States in the 1920s. The links between racism and creationism became explicit during *Epperson v. Arkansas*, in which the US Supreme Court ruled that laws banning the teaching of evolution in public schools are unconstitutional. Today, the relics of racism, evolution, and creationism persist in many forms, ranging from books such as *The Bell Curve* to educational institutions such as Bob Jones University.

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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.

On Two Dark Rocks

By: Louis Rosenblatt, The Park School, Brooklandville, MD, USA lrosenblatt@parkschool.net

There was a time, years ago, when I went hunting for dinosaurs. That's pretty extra-ordinary, hunting for dinosaurs, at least it was for me. I could remember the *Golden Book of the Big Dinosaurs* when I was a kid--their monstrous size, the violence in their eyes, their fierce step. There were always volcanoes smoldering in the background. It was a completely foreign and exotic world. Yet, it was also a real world. Perhaps this is the key to their mystique. They were dragons that actually stomped about and breathed their fiery breaths. That's the appeal of all those marvelous tales, like James Hilton's *Lost Horizons* or Michael Crichton's *Jurassic Park*, where hidden away in lost corners of the globe are the last descendants of the lumbering beasts of the Mesozoic Era.

That lost world of the dinosaur is all around us, and I was going to find it. Not by myself, mind you. I was going with Robert Bakker, a great dinosaur hunter. We were going back, in fact, to the mid-Jurassic, to the Morrison formation--rocks of a characteristic type deposited 150 million years ago but presently found all around you if you happen to be in parts of Colorado and elsewhere.

So, we set off to find our great beasts lumbering through swamps, locked in deadly combat, and of course, there would be volcanoes smoldering in the background. When we got there, what we saw was quite different. Instead of steamy swamps, we were confronted by a barren and bleak hillside. We were at a site near Grand Junction, Colorado, in the Western range of the Rocky Mountains, close to the Utah border.

The key is to superimpose these two scenes. Here is the measure of the difference between facts and arguments. Here we are, reason tells us, knee-deep in the world of the Iguanodon and the Brontosaurus (or Apatosaurus), with Pteradactyls in the skies, flanked by Tyrannosaurus Rex in battle with a Triceratops, the great plebian warrior, with giant ferns and smoldering volcanoes, and what do we see? What are the facts? A bleak, bleached-out hillside!

After several minutes, I realized that everyone else in our small party had found a fossilized morsel to relish, and that all I had been able to do was swat at the predatory gnats that are a large part of the modern environment. Determined not to let the moment escape, I opted for the beaten path, and began to search for some sign of ancient life in the rocks just a few feet to the right of where Bakker had found something.

The hillside was composed of a soft, crumbling sandstone that had a crust like the kind that can form at a beach; as though it had rained and then had dried. I clambered along the slope, chose my spot a respectful distance away, and began to scrape at the surface. Success! I found two smallish lumps of dark rock! I called out to Bakker and he came over right away. “Ah,” he said, “a great find. It looks like two vertebrae of a Camarasaurus.” I had done it. I had found the remains of an ancient beast. The Camarasaurus was a beast of that broad, sleek Brontosaurus or Apatosaurus design, though quite a bit smaller. Its remains are not uncommon in the Morrison, and there are some lovely specimens on display at Dinosaur National Monument not too far away in Vernal, Utah. Then, right at the height of my joy over my great discovery, I learned we had to go. I was shattered.

I wanted to cry out “Wait!” but I knew it was no good. Bakker was, unfortunately, quite ill, and ought not to have gone out in the first place. And so they packed up their goods and made for the car and the ride back to town. I was left standing there in a daze, staring at my two lumps of dark rock; for that was all they were. I wasn't going to have the chance to bring them to life. The reality they constituted would continue to be a private affair between them and their setting. I hadn't found vertebrae; I'd found two dark rocks. To make them the vertebrae they really were would require work, and that's the moral of the story. As we go through life, all we experience is the appearance of things, and appearances are a long way from reality. Getting down to reality has a lot more to do with informed flights of fancy and the capacity to follow where reason leads. The real world takes time and work. It takes analysis and a well-schooled imagination, . . . but I was already lagging behind. So I, too, picked up my gear and headed back toward town.

There are, of course, wonders to nature like the Grand Canyon or the Great Barrier Reef where we are overwhelmed by nature’s colors and proportions. But there are other wonders, like black holes and ice ages and the intricacies of molecular genetics, where the colors and proportions rest in our reason, in our capacity to conjure up what things might be like as dictated by argument and analysis. Without this reasoned imagination, so much of our world would be bleak and bleached out.

John Playfair caught this imaginative quality of reason as he wrote about a geological tour with his friend and master geologist, James Hutton. Visiting Siccar Point, they realized how vast a span of time had been at work in creating this landscape, and Playfair (1822) observed: “We became sensible how much farther reason may sometimes go than imagination can venture to follow” (p. 81). When we marvel at the intricacies of the world of electron microscopy, or at the vastness of distant nebulae “dying in the corner of the sky,” we are carried to these fantastic worlds, not by the imagination of the poet, but by the careful reasoning of the scientist making sense of the world.

One further note. Whenever I am working on what I ought to teach next, and how, I go back to that landscape. Staring at those rocks, I realized the material doesn’t speak for itself. My job is to get kids to appreciate the wonders of reason and how even in a barren landscape, in two dark rocks, you can find the drama of fire-breathing dragons.

Reference

Playfair, J. (1822). *The complete works of John Playfair* (Vol. 4). Edinburgh: Archibald Constable and Company.

Science Poetry

Reading and/or listening to poems that have been 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 .

Science is . . . ?

Science can be hair-raising
As if you didn't know,
Charge up the electrical field
And up your hair does go.

Science can be sickening
When you dissect a rat,
Pull the insides out
And then you lay them flat.

Science can be smelly
When in the lab one day,
You combine the right ingredients
Rotten egg gas comes your way.

Science can be infinite
Just look up to the stars,
On forever it does go
On it's way past Mars.

Science can be frustrating
When things become a pain,
A small mistake at the wrong time
The results go down the drain.

Science can be harmful
If you're a mind for stupidity,
Rules are to be followed
Or all will be in jeopardy.

Science can be int'resting
Encompassing many fields,
Can't find something to enjoy?
You're too hard to please.

But if you're really honest
You then must admit,
In the vast field of science
There's a lot of fun in it.

Jade Salmom, 13 years
Australia

The Brain Train

Would you go traveling inside the brain?
I actually thought it would be a pain.
But it was really cool,
And to think we learnt it in school!

Come with me,
And we will see,
Some of the little things,
That keep us learning.

Omega 3, Omega 6, protein and fat,
These are the foods we need to eat, it really is just that.
Carbohydrates and micronutrients should also be on the plate,
Otherwise, for our clever brains, it will be too late.

The Amygdala is the brain center for emotions,
To keep it healthy, we must have a certain food devotion.
Some of the emotions are happy and sad,
Others are crazy and mad.

The cerebellum is really big,
It helps me remember how to dance a jig.
It makes sense of information coming from our eyes and ears,
One of the things it doesn't do, is control our fears.

Some people think,
The brain is just soft and pink.
Others say it's lumpy,
And really, quite bumpy.

To travel around inside the brain,
We need to catch the neuron train.
To whiz past the synapses and the neurotransmitters,
Would cause some people to get the jitters.

It was a very long train ride,
To see the brain from side to side.
Write down the things that you found out,
Write them quickly, 'cause we need to get out.

Amy Rathmell, 11 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.

When it gets hotter, the mercury in a mercury thermometer rises because the heat energy:

(a) causes the mercury particles to expand and take up more space.
(b) transforms the mercury particles into particles of another substance that are lighter and occupy more space.
(c) pushes the mercury particles, causing them to rise up and occupy more space.
(d) causes the mercury particles to move, or vibrate, faster, resulting in them occupying more space.
(e) I have a better idea. (Please explain.)

Comment: Option d is the correct one.

Adapted from: Gómez Crespo, M. A., & Pozo, J. I. (2004). Relationships between everyday knowledge and scientific knowledge: Understanding how matter changes. *International Journal of Science Education*, *26*, 1325-1343.

Teaching Techniques

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

To Your Corner

Display a statement or question to the class, or present a demonstration scenario. Without discussion, ask students to take a position in relation to the matter (e.g., *Strongly Agree*, *Agree*, *Neutral*, *Disagree*, or *Strongly Disagree* or, in the case of a demonstration, to choose one of a series of alternative predictions about the outcome of the demonstration, including *I Don't Know*. To avoid students simply following a friend in the next step, they might be asked to write their choice down.

Invite them to move to a position in the room (there might be three to six such positions, say) designated for those taking a particular view, and to share their reasons for taking that position with others in their group. A bonus here is that the teacher can quickly gauge overall class thinking on the issue. In the case of a group being large, have students begin exchanging their ideas in smaller groups of 2 or 3.

Each group then shares their ideas with the whole class, and this might be accomplished in any one of a number of ways. For example, a recorder in each group might be asked to write the main ideas of the group on a chart or overhead transparency, a pair of students might be chosen randomly to report to the class, or a selected group spokesperson might perform this task.

In the case of a demonstration, perform the demonstration and then ask students to use their observations to evaluate their initial predictions. A possible variation would be to assign students to a particular position, and invite them to think of reasons for supporting that stance.

Ideas in Brief

Summaries of ideas from key articles in reviewed publications

Interview Assessment

Interviewing students, in their groups, after labs can be most beneficial (Coan, 2005). Knowing the interview will occur increases students' interest in, and motivation for, both doing a lab and completing the associated calculations correctly. They ask more questions during a lab, work more carefully, and learn more from the activity than is the case when they simply write a lab report.

When introducing lab interviews, provide students with a list of possible questions in advance. Do not do this subsequently, thereby encouraging students to predict what they might be asked. Questions might include:

- What was the aim of the activity?
- In your own words, what procedure did you use?
- Why did you . . . ?
- How was . . . obtained?
- What sources of error are there in this experiment?

With a maximum of 3 students per group and 10 questions, say, prepared, each student in the group might be required to correctly answer at least one question to be awarded a pass grade. The interviews are ideally conducted during the lesson following the lab, but this is also time consuming and requires students in the class to be also set some other task. Rather than interviewing every group after every lab, time can be saved by interviewing a random selection of groups only after each lab, with those students not interviewed after a particular lab being required to answer the same questions in their lab reports.

Reference

Coan, A. (2005). Interview assessment. *The Science Teacher*, *72*(3), 64-68.

Using Projects to Stimulate Learning

Wilson (2004) recommends the use of projects that are linked to the unit (s) being studied. These original pieces of work may be from a variety of categories that include an experiment, writing (including creative writing), art, a model, poster, song, dance, computer slide show, or book or article review. For especially students interested in a career in education, an educational tool such as a study guide or pre-test is suitable. Each student might be required to complete a project for each unit of work (the projects being used as a culminating activity), or to complete one project per term, say, with the projects being presented as the relevant units are covered.

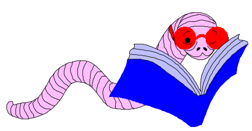
The following suggestions may help implementation of the projects:

- List the units to be studied during the term, together with suggested project categories.
- Display sample projects, and the scoring of them, from previous years.
- Discourage students from choosing the same project category too often.
- Materials need not be expensive, and may be a combination of teacher- and student-supplied.
- Have a whole-class discussion at the beginning of each project class, so all students hear the questions and answers.
- Avoid having any two students doing exactly the same project. Alternatively, for larger classes, students might work in teams.
- When most students are close to finishing, have them complete their projects for homework.

Each project ends with a presentation by the creator(s), whereby he/she teaches the other students in the class. The presenter(s) prepares a short assessment (e.g., a quiz or game) for the audience, and members of the audience score the presentation using the same rubric being used by the teacher. This motivates the presenter, and helps engage the audience. The rubric might have sections for the product, oral report, and assessment tool, and also provide space for brief comments that justify the scores given.

Reference

Wilson, S. (2004). Creative projects stimulate classroom learning. *Science Scope*, *28*(2), 41-43.



Research in Brief

Summaries of research findings from key articles in reviewed publications

Using Science Fiction Stories to Assess Students' Ideas About the Nature of Science

By: Pedro Reis, Universidade de Lisboa, Lisboa, Portugal
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Almost every day, controversial socio-scientific issues are raised by the media: genetic engineering, cloning, experiments on animals, and so forth. To study possible impacts of recent such issues on students' conceptions about science and scientists, Reis and Galvão (2004) used a questionnaire, science fiction stories written by the students, and interviews.

Eighty-six 11-th grade (17-year-old) Portuguese students studying Earth and Life Sciences, from five classes in two secondary schools near Lisbon, took part in the investigation. Participants: (1) answered a short questionnaire, with open-ended questions, aimed at gathering evidence concerning their conceptions about recent socio-scientific issues (related to science and technology) and the way these issues are addressed in the classroom; and (2) wrote a science fiction story, as an individual homework task, that involved a group of scientists working on a specific situation of their choice. After reading both the questionnaires and the stories, the researchers interviewed 17 of the participants to explore in detail the ideas integrated in their answers and the plots of their stories.

The story plots represented a complex combination of: a) students' ideas about science and scientists; b) images taken from the media, science fiction films, and books; and c) some elements that students identified as being part of a good science fiction story. Therefore, analysis of the story plots did not provide direct access to students' conceptions. Rather, it simply offered evidence that needed to be further probed through interview.

The socio-scientific controversies recently discussed in Portugal (cloning, treating toxic waste, consuming genetically modified foods, etc), and the way science and scientists are reported in the media, seem to have reinforced the ideas that science and technology are human enterprises: (1) influenced by values, personal agendas, and financial and social pressures, (2) that represent a simultaneous source of progress and concern, and (3) should be ruled by ethical and moral principles and assessed by citizens and the State.

Some of the stories' plots were clearly influenced by wrong ideas and distorted images about scientists (for example, the stereotypical caricature of the eccentric scientist working alone in his lab on secret and dangerous projects) frequently transmitted by films, cartoons, and comics. This stresses the important role of science classes in the discussion of ideas and images on science and technology conveyed by the media. Only through a better understanding of science, and of scientists' activity, may we aspire to reduce the number of merely emotional negative reactions citizens have regarding scientific and technological innovations, and to motivate students towards a future career as scientists. The classroom discussion of science fiction stories, written by students, can be quite useful for the analysis of students' conceptions about science and scientists and the deconstruction of stereotypes and wrong ideas conveyed by the media.

Reference

Reis, P., & Galvão, C. (2004). Socio-scientific controversies and students' conceptions about scientists. *International Journal of Science Education*, *26*(13), 1621-1633.

Readers' Forum

Cartooning to Engage Students

The question, in the last issue, about getting students' attention reminded me of my dissertation project, during which I needed to teach science to a group of ninth-grade (14- to 15-year-old) Indian students. The project aimed to teach them meaningful, as opposed to rote, learning. The students came from various socioeconomic strata. Many of them were first-generation learners, meaning that their parents had not received any formal education, as they belonged to the lower socioeconomic strata. I explained that I needed a sample of volunteer, ninth-grade students, that my project was not a part of their school routine, and that their attendance was not compulsory. Those who wanted to attend my class would have to do so after attending 6 hours of regular school.

When I began, I told the students that I would teach them using cartoons, and that they would be free to answer the questions using cartoons of their choice. Instantly, I saw their faces brighten up. They had quizzical expressions on their faces, as they had never heard of such a thing before.

I was supposed to teach five or six lessons from their science textbook. I prepared charts for the first lesson, charts containing pictures and keywords. There were no sentences. For example, the phenomena of attraction and repulsion between atoms were depicted as atoms pulling and kicking each other, respectively. The charts for subsequent lessons were prepared with the help of the students, who participated enthusiastically. They enjoyed each and every session, and there were no dropouts.

I think that telling the students that they would be taught science using cartoons, and that they would be free to answer in the same form, grabbed their attention instantly for reasons that perhaps include the following:

1. Teachers rarely use imaginary pictures or cartoons to explain science concepts. When they do, it is most often in primary classes.
2. When concepts are explained to students verbally, sometimes they are not understood. By offering an alternative, cartoon forms help students visualize concepts.
3. Cartoons stimulate the imagination of students, at the same time providing an element of challenge that they like to take up.
4. While writing answers in science, students are expected to follow certain norms, like using specific terminology, and they may not express in the language they want. Hence language is a barrier and the process is rigid.

Such obstacles do not hinder the answering process when cartoons are used. Also, to be able to draw cartoons, one need not have good drawing skills.

Vidya Hajirnis, India

? ? ? ? ? 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!

Getting Students' Attention (continued from the previous issue)

What way(s) have you found effective for getting all students in a class quiet and listening within 10 seconds? (*Editor:* This question relates to Item 1 of the Inquiry Classroom Management Checklist, p. 27 of this volume.)

At the start of each Biology lesson, I read a section from Obstfeld (1997) (although many other resources could serve the same purpose), a book concerned with bizarre behaviours--mostly sexual, as most behaviours ultimately are!--of various animals. The students become quite addicted and don't let me start without reading from the "Animal Book," and I get to start a lesson with pupils who are engaged and amused. If certain students don't settle and listen straight away, their fellows shush them pretty quickly so that they don't miss out. This is as opposed to starting with a marking of the roll, which sets a tone of procedure, administration, and box-ticking. It also provides me with opportunities to discuss animal behaviour in a course that doesn't always give this topic a unit of it's own. And, we always start with a laugh!

Reference

Obstfeld, R. (1997). *Kinky cats, immortal amoebas and nine-armed octopuses: Weird, wild and wonderful behaviours in the animal world*. New York: HarperPerennial.

Geoff Fletcher, Mt Maria Senior College, Mitchelton, Queensland, Australia

To keep noise levels minimal, or to get the attention of every student, a simple turning off and back on of the overhead lights is all that is generally required. When the lights go off, students know they need to be quiet and listen. If they are actively involved with an experiment, flick the lights off and back on quickly. If they are doing a non-physical, less critical activity, the lights remain off until all are quiet.

Terry Keck, USA

I use a tuning fork, or chime, to signal that I need student's attention, and wait in my "teaching spot" while the students remind each other to pay attention. With some time spent on training them in classroom procedures, students respond rather quickly.

Jennifer Echtle, USA

Gaining attention is about teaching and learning a required behaviour (i.e., a response). Gaining attention quickly, and as completely as is required, becomes a problematic behavioural science experiment. Especially over the last 2 decades, teachers have had to be diligent in facing this challenge, using more contemporary strategies that consider cultural and social shifts. The diversity that exists within the social context of a classroom requires teachers to develop and apply a number of practical behaviour management strategies. How teachers approach behaviour management within the classroom will depend on their ideology, as well as their understanding and application of the various learning theories. Behaviour management strategies are constantly tempered with the years of teaching experience. The strategies used will also depend on students' developmental stage (rather than simply their age).

I have found an action-consequence approach to work with my Yr 6-7 class. It is quick to deliver and learn. If students are too noisy, or I want them to stop and give me their attention, I count down from 5. If by zero I am still waiting on even 1 student, I put a chalk mark on the board. This acknowledges that it is unreasonable to just expect anyone to instantly stop what they are doing, but also that it is unreasonable for people to have to wait forever to have a say. Three chalk marks and the class remains in for a minimum of 5 minutes. This gives students time to make the behavioural adjustments through their own experience. Resistant individuals are addressed as a separate issue.

I make variations on my count-down methods. I introduce this behaviour management strategy with a loud voice so all can easily hear. As students get used to the technique, I vary the volume of my voice, sometimes just lip-sinking the words (i.e., no volume). I will also use my fingers, again with no accompanying noise. I discuss this with the class as a way of training the students' observation skills, essential for inquiry-based lessons and general social courtesy skills (respect, manners, etc.).

I have thought about, but not yet tried, a variation on Edward De Bono's six thinking hats, with the colours signifying particular teacher requests (e.g., quiet and attention to the front, I'm now available to answer questions, students to be working quietly, group work, independent work, and time to ask other groups for help). A top-hat style might initially display the written request, getting students used to the strategy. The written prompt might be later removed, with the colour of the hat alone signifying the behaviour to display (akin to Pavlov's dog experiment). Coloured posters, identifying the associated behaviours, might be placed on the walls. Students could use coloured paper to construct the hats.

Such a strategy could engage the students in the whole process, and also incorporate mathematics (e.g., measuring the circumference of the teacher's head [string method or cloth tape measure?];

leaving enough on a circle to make the brim; surface area of the brim, cylinder, and top circle (if required); diameter and radius of the teacher's head; volume of the teacher's brain (Years 9-10); volume of brain in use if we use only 10% of it; average mass of an adult brain (library or internet research); volume:mass ratios to calculate the “dead weight” of the teacher's brain (comparing known weights with known objects, such as fruit, to provide a better frame of reference). Science might be discussed, with a focus on matter, mass, and weight (i.e., the force due to gravity).

The associated behaviours could be typed using a computer, thus integrating ICT. Students could select the “appropriate” colour for a particular behavioural request, thereby involving them in the construction of the behaviour management strategies used in the classroom. An invited guest (e.g., Principal, Deputy Principal, Head of Department, or parent) could judge the best hat in each colour, requiring the teacher to do a fashion parade in front of the class. The winning hats would be used by the teacher, with the rest being displayed in the class.

This appraoch sounds like a lot of work, and it would be (perhaps a term to complete the process). Would the time, effort, and expense be worth it? I would hope so. Would there be long-term benefits for behaviour management, motivation, and student outcomes? I would hope so. Such a drawn-out approach would better suit a traditional primary classroom situation, or learning support group, more than a traditional secondary classroom situation with less time flexibility. However, tradition should never stifle a teacher's creativity.

Richard Cooper, Allora State School, Queensland, Australia

Evolution and the Origin of Life

I understand that evolution refers to a change in gene frequency over time. However, does the theory of evolution have anything to say about the origin of life? If not, what (scientific) hypothesis or theories do we have in this area?

Before I answer what essentially is a two-fold question, there needs to be general consensus on the difference between the principle, or law, of evolution and the mechanism, or theory, behind evolution; that is, natural selection. Definitions in science are important. In science, we use terms such as scientific law and theory. Both are related to each other, yet they are distinct in what they try to reveal. A scientific law is a general statement about an observed phenomenon in nature. For example, the statement mentioned in the question, “evolution refers to a change in gene frequency over time,” is a general statement about the fact, or law, of evolution. Another example of the law of evolution would be the statement that organisms change over time. Both these types of statements are just that, statements about organisms and how they change over time. Scientific laws such as these do not, though, provide an explanation, or mechanism, as to how organisms change over time. A theory in science provides us with this; an explanation for how the observed phenomenon, or law, takes place. The theory of evolution by natural selection provides us with a mechanism for evolution. It does not explain, nor does it pretend to explain, the origin of life!

A misconception, in which biological evolution is placed side-by-side with the origin of life, exists among many people. The two are conceptually separate. As a matter of fact, most people believe that the *Origin of Species* by Charles Darwin is about the origin of species. No! As noted above, biological evolution is the descent of living things from ancestors from which they differ. Scientists have a vast amount of empirical evidence for both the law of biological evolution and the mechanism, or theory, of natural selection; specifically, the origin of microevolution, leading to macroevolution or speciation. Life had to precede evolution. As a result, research in prebiotic evolution is ongoing and rigorous. Numerous hypotheses exist as to how life began (e.g., the Oparin-Haldane Model and the building of RNA and nucleotides). However, the scientific community is still gathering and debating the data and evidence needed to support a mechanism/explanation, or theory, of the origin of life.

Paul Narguizian, California State University, Los Angeles, CA, USA

I would answer as follows: The origin of life is a separate issue from the theory of evolution, although the boundary is gray. The answer to the question really lies in the meaning of science itself. The Theory of Biological Evolution By Natural Selection addresses change in living (and once living) species. It is a theory precisely because it provides a broad framework for the explanation of a process through observation and experiment. In addition, the theory is upheld time and again by new information, as the tools of science become available to probe more deeply--even at the molecular level. In this way, the theory is strengthened even further.

Ideas about the origin of life are best placed in the category of hypothesis (a possible explanation) at this time. Several factors prohibit us from raising the issue to the status of theory. In terms of science, we can only address the suggestion of a natural origin of life (as opposed to a supernatural one). In this regard, experiments conducted have shown fairly conclusively that conditions on the young Earth would have favored the formation of complex organic molecules. The fragility of chemicals leaves us no direct clues about the transition from nonliving to living matter. Since the transition may have taken hundreds of millions of years, it would be difficult to generate data that would analyze this transition. It is important, however, to teach the hypothesis of abiogenesis to our students, because it illustrates the dedication of our discipline to look for natural answers to questions about nature.

Edward Neubauer, USA

Evolution means change. Organic evolution refers to changes observed when observing living organisms. Change in gene frequencies over time is genetic, or molecular, evolution, and it is the mechanism that contributes to changes in anatomy, physiology, behavior, and so on. The most important theory developed by Charles Darwin is natural selection. It describes a mechanism that can cause changes in gene frequencies and the resultant expressions of those changes. There are other mechanisms that result in changes in gene frequencies as well.

Origin of life is a necessary event in order to have organic evolution. Life forms had to come from somewhere. Hypotheses of biogenesis suggest that a series of chemical events led to a primitive form of life. Depending upon how you define life, the evolution of genetic systems may mark that point in history. What happened before then would be chemical evolution that resulted in an origin of life. Science does not yet have well-supported theories as to what happened at that point in history, but there is evidence that bacteria were present on the planet over 3 billion years ago. If you choose to believe that God was responsible for creating the first life, scientific evidence suggests that this act took place about 4 billion years ago, and then life evolved by well-supported mechanisms to the systems we observe on earth today.

Some also bring the formation of the stars, planets, solar systems, and universe into discussions of evolution. It would not be incorrect to call this evolution, but it is not organic, or biological, evolution. It is not what Lamarck, Huxley, or Darwin were thinking about. This issue falls within the discipline of cosmology, not biology or geology. Evolution is a very broad term. I think it would be appropriate to talk about a science (or sciences) of evolution.

George E. Stanton, USA

Evolution does refer to change in allele frequency over time, although this is a narrow definition. More broadly, it refers to the change of living things over time. Changes in allele frequency are one aspect of the mechanism.

In discussion with non-biologists, it is likely that this definition will not seem right. Currently, creationists consider this definition to refer (correctly) to microevolution. However, they tend to state that microevolution is not evolution--it's just "change within kind." They object to the overall pattern of evolution, which we refer to as the pattern of common descent, and they refer to as macroevolution. That is, they accept microevolution, but not common descent. The former has been proven beyond a shadow of a doubt; they can still find ways to doubt the latter.

Non-biologists also tend to lump the origin of life and the origin of the universe into their notion of what evolution covers. The origin of life, in discussions with creationists, is generally referred to by the name *abiogenesis*--life arising from non-life. Perhaps, this term is used to make it sound like spontaneous generation and to contrast it with normal reproduction of living things. Either way, it does cover the issue pretty succinctly. Chemical reactions became organized, eventually developing a replication mechanism--life from chemistry.

It is important to separate evolution of life, once it arose, from the origin of life. We understand a great deal about the former. Understandably, we know rather less about the latter. It is appropriate to tell our students that we really don't know how life arose, but that we have some good hypotheses that build on the data that are available. We will undoubtedly abandon these hypotheses and develop new ones, as new data become available. However, once life did arise, and nucleic acids became the repository of genetic information, then evolution had little choice but to follow the mechanism that we now understand--from the earliest single-celled life forms to us.

J. Jose Bonner, Indiana University, IN, USA

This is a great question that, to my knowledge, science has no answer to today. In my opinion, the real question is the definition of life at the beginning of life. In his book, *Oxygen: The Molecule That Made the World*, Nick Lane relates the story of the Spiegelman "monster." In 1967, Sol Speigelman tried to discover the minimal amount of material that could be "alive." He began with a very small virus that had about 4,500 codons in its genetic material. By providing all of the materials necessary to reproduction in a test tube, he was able to get the virus to grow without being in a cell.

Some mutations eliminated genes that were no longer necessary to survival because the laboratory medium provided the materials coded for by the gene. Because the mutated virus was smaller, it reproduced faster and replaced the original virus. The virus eventually became just 220 codons long and was still reproducing--now at a furious rate.

Imagine the medium in which the virus is reproducing being diluted. The virus will still reproduce, but at a diminished rate. If you could create a large, sterilized environment with the necessary chemicals and the 220-codon virus, it would continue to reproduce even if the chemical concentrations were very dilute and even if some chemicals were absent much of the time. The virus, having nothing else to do, would simply wait with incredible patience for the right molecule to come along.

Realizing that the Earth spent about 4 million million years before multicellular life appeared, you can see that the early lifeless Earth could have been a fine place for a chemical similar to Spiegelman's "monster." Once a molecule like it appeared, it could have taken years to find all the ingredients for reproduction, as long as nothing happened to destroy it. Even at this slow rate, it would have reproduced, mutated, and become more efficient at reproducing--the primary purpose of life. Yet, this molecule would hardly be called life by most people, and would not survive for a moment outside of the laboratory today.

The theory of evolution and genetics posit a creature known as LUCA, the Last Universal Common Ancestor. It's described as a bacterium, but it might be something even simpler. DNA database analysis suggests that all life has some genes in common, and that these genes must have originated with a single simple ancestor that survived and, almost literally, conquered the world leaving no competitors alive. We don't know what this LUCA was, or what (or even if) its competitors were. We can only infer that a single bit of life about 4 million million years ago became the progenitor of all life on Earth today. To my mind, the quest for LUCA is an exciting adventure of the magnitude of discovering planets around distant stars, or the nature of "dark energy," or the origin of the human species.

Harry Keller, CA, USA

I teach General Biology in a High School in Alaska. My approach to teaching evolution is based on molecular biology, and as you say, the change in gene frequency in a species as a result of selective environmental pressures (natural selection). As such, the requirement of a genetic molecule that controls cellular metabolism (discussed as the chemical reactions that we know as "Life") is essential. In my classroom discussion, students are asked to analyze whether the current theory of evolution includes origin of life or not, and we use the works of Fox, Oparin, Miller, and other scientists for reference.

In general, the understanding that usually develops is that evolution proposes a possible, evidence-based explanation for the change in organisms from a probable common ancestor(s) that contain some form of a genetic molecule regulating both cellular energy and reproductive action. From this foundational discussion, it seems that the origin of life and discussion of biogenesis are separate from the topic of evolutionary change in organisms leading to the diversity of life that has existed on earth.

It is interesting to note that I understand that this topic is often discussed around "the camp fire" and "under the stars" when students gather in their social enclaves outside of the classroom. Is this not the goal of education: for students, the next generation, to own, discuss, and seek the answers to the oldest questions?

Robin Schaeffer, Alaska

This opens the deepest can of worms in the theory of evolution. If we accept, for the sake of this question, your definition "evolution refers to a change in gene frequency over time," then we have the following conundrum. Before there were genes, there was no meaningful gene frequency, and thus no evolution.

The key is to note these loopholes:

1. Genes are defined in terms of DNA, and it is considered likely today that there was an "RNA World" before DNA came into being. Your question thus leads to the question: "What does the theory of evolution allow us to infer about the RNA World, before DNA existed?”

2. In Darwin's theory of evolution by natural selection, we have a causal mechanism defined for species, in terms of interactions between individuals of that species and the environment. However, modern results by Carl Woese and others suggest that there was a time when species as such did not exist, as gene transfer between different types of organisms was as common as gene transfer between two individuals of the same type. That is, the "tree of life" does not have a single trunk, but a tangle of interconnected roots.

In the sense of these two loopholes, we are led to questions of how the Genetic Code (from DNA to RNA to protein) evolved. We cannot directly extrapolate back to when there were multiple different genetic codes, only one of which (with slight variations) exists today. Totally different genetic codes may have existed in the "primordial soup" of early biotic oceans, lakes, or ponds or, in another recent hypothesis, inside rocks. But these are so totally extinct as to have left no distinguishable records.

There are a few theorists who believe that we may use sophisticated mathematical methods to extrapolate back to when there were multiple different genetic codes. I am in touch with one such mathematical biologist, discussing a possible coauthorship.

There are also mathematical models of prebiotic evolution pioneered by the hypercycle model of autocatalysis by Dr. Stuart Kauffman. Experiments by Dr. Leonard Adelman on artificial replication of RNA seem to show that something akin to Darwinian evolution can happen to naked RNA. For example, if one exerts selection pressure on RNA to self-reproduce as fast as possible, one gradually gets shorter and shorter strands of RNA, up to a limit beyond which self-reproduction is barely possible.

In conclusion, the question becomes one of meta-evolution: "What was the evolution of evolution?" There is no answer yet, but there are several different avenues of theoretical and experimental exploration. If we have data points of life that independently evolved on other planets, we might make very rapid advances in understanding meta-evolution.

Jonathan Vos Post, Computer Futures, Inc., Altadena, CA, USA

Further Useful Resources

The Fascinating Body: How it Works http://www.fascinatingbody.com

Learn biology in context. This book, by Sheldon Margulies, M.D., uses questions and answers, concerning everyday experiences and observations about the human body, to teach how the parts and systems of the human body work and to motivate teenagers to learn the underlying anatomy and physiology. Also serves as a family book for adults.

National Whiteboard Network http://www.nwnet.org.uk

What is an interactive whiteboard, and what potential benefits does this technology provide?

Cell Division Program http://www.cell-division-program.com

The first animated computer simulation of cell proliferation in a living tissue. The program is designed for research in cell biology and development, and should serve as an excellent tool for classroom demonstration. It is based on spatial requirements inherent in the structure of the living tissues, and takes into account the long-neglected, although well-known, fact that any living tissue represents an integral structure having a tissue-specific architectonics and composed of interconnected cells.

The program models cell proliferation, cell movement, and growth in the crypt of intestinal epithelium, and it allows tracing every cell in the crypt. The rates of cell division and growth can be varied, and the two processes can even be uncoupled. It also allows constructing other tissue models with widely different structures. Some structures will display growth and, in fact, will "develop" themselves, increasing the complexity of their structure. The results obtained suggest proliferation patterns of stem cells that so far have escaped the attention of cell biologists.

Pavement Drawings http://users.skynet.be/J.Beever/pave.htm

These illusions, by Julian Beever, which give a three-dimensional impression, exemplify the limitations of our natural senses in collecting data.

Scientific Inquiry Scoring Guide http://www.ode.state.or.us

A rubric, produced by the Oregon (US) Department of Education, for assessing student performance on inquiry-based lessons. Use the *Subject*, *Science*, and *Assessments* links from the above page.

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