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# THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

## Did you Know?

### *The Size of our Solar System*

Classroom charts misrepresent the size of our solar system. The solar system comprises the Sun, the eight planets, their moons, three dwarf planets, including Pluto, and their four moons, and billions of asteroids, comets, meteoroids, and pieces of interplanetary dust. While Pluto is shown as the outermost object on classroom charts of the solar system, it is barely one five-thousandth of the way to the edge of our solar system.

## Teaching Ideas

Techniques, demonstrations, activities, alternative conceptions, critical incidents, stories, and other ideas

### *Science Story: God's Rocky Drafts*

At the time, over 2.5 centuries ago, when fossils were first being regarded to be the remains of extinct species, Professor Johan Beringer was working at the University of Wurzburg, Germany. This interpretation conflicted with his religious views, which saw him believing that fossils were drafts made by God while designing the great variety of species that He was to create.

Berlinger presented his theory in what was to be his life's greatest achievement, a huge treatise complete with illustrations of his fossils. Of course, his latest and most exciting finds were included. One fossil depicted a bird with a fish's head, presented as evidence for an idea that God had decided not to pursue further! Other fossils were similarly so bizarre that it should have been obvious that someone was "pulling his leg." However, Beringer had become so emotionally attached to his idea, and so used to criticism, that obstinacy had become a habit.

As a result of a prank that went too far, Professor Berlinger was about to find his career shattered and become a broken man. Upon rejoining two halves of a broken fossil, he found his name spelt out in the carved rock and realized his stupidity. He spent his life's savings searching for, purchasing, and destroying copies of his published book. A university inquiry identified the Professor of Geology and a librarian as the pranksters. They had carved "fossils" and deliberately left them for Berlinger to find.

### *The Business Card*

This activity can be used to identify students' interests, make connections between these and the science they are learning, and demonstrate that including students' interests in Science is important. As one of the first homework tasks of a course, provide each student with a 4-inch x 6-inch index card and ask them to use it to prepare a business card for themselves in a future career they would like to have. The front of the card should show the career title, the student name, and a graphic created to represent the career. On the back should be two brief statements, one describing how the student thinks the career relates to science and the other describing where the student's interest in the career originated.

Paste the business cards on a prominent bulletin board in the classroom. Use the cards when planning science units (e.g., as entry points into a unit). Where possible, explicitly connect the science being learned in class with the student interests reflected by the business cards.

*Source*: Beeman-Cadwallader, N., Quigley, C., & Buck, G. (2010). Fix the potholes! Helping students translate their interests and life experiences into scientific investigations. *Science Scope*, *33*(8), 42-46.

## 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 .

### Light and Colour

Rainbows appear
when sunlight passes
through raindrops
after the rain.

I often wonder
how I could catch the colours
bottle them up
for another day.

The colour of light
is a wonderful science
creating a spectrum
that will give you delight.

Red, blue and green
are the primary colours
mix them together
gives you sheens of white.

So when the rain comes

### The Life Aquatic

My text on ocean sea life
Has taken centre stage
With the most amazing creatures
Gracing every page.

The enigmatic seahorse
Is favoured 'mongst the crew
The father births the babies
An astounding thing to do!

I pity the poor stonefish
With his thirteen deadly spines
And his discontented visage
As he lurks in muddy brine.

In contrast, there's the clownfish
Who presents as quite quixotic
And forms a strange relationship
Described as symbiotic.

Villains like the great white shark

look for a rainbow
a mirage of colour
that lights up the sky.

But always remember
the colours are fragile
ready to vanish
at the blink of an eye.

*Hana Hampton, 9 years*
*Australia*

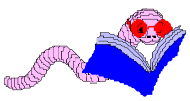
Prowl through the oceans deep
While pods of noisy dolphins
Cavot, gambol and leap.

Sponges, mollusks, fish galore
Sea urchins and cucumber
Fill the seas and oceans
With wild life beyond number.

There's something mesmerising
And soothingly hypnotic
About the oceans' ebb and flow
About life aquatic.

I feel a wistful yearning
Growing harder to withstand
To leave the textbooks far behind
And view it all firsthand!

*Jack Burnham, 15 years*
*Australia*



# Research in Brief

Research findings from key articles in reviewed publications

## *Synthesis of Inquiry-Based Science Instruction Research*

What is the impact of inquiry science instruction on K-12 student outcomes? Minner, Levy, and Century (2010) addressed this question by synthesizing the findings from 138 research studies conducted, primarily in the United States, during 1984 to 2002. While the synthesis did not show an overwhelming positive effect, inquiry-based instructional practices, and particularly those emphasizing active student thinking and the drawing of conclusions from data, showed a clear and consistent positive impact on students' conceptual understanding.

It was not found, though, that overall high levels of inquiry saturation were associated with more positive outcomes, and this is an area suggested for further research. However, in the current environment of standardized tests based on wide topic coverage, more passive teaching techniques are often necessary.

*Reference*

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction–What is it and does it matter? Results from a research synthesis Years 1984 to 2002. *Journal of Research in Science Teaching*, *47*, 474-496.

## *Effectiveness of Inquiry-Based Instruction*

Wilson, Taylor, Kowalski, & Carlson (2010) investigated the effectiveness of inquiry-based instruction by comparing the outcomes for 58 students, aged 14 to 16 years, assigned to one of two groups; one group taught using an inquiry-based (5E) model and the other taught using commonplace strategies as defined by national (United States) survey data. Each group of students studied a unit titled Sleep, Sleep Disorders, and Biological Rhythms during a 2-week summer course.

The inquiry-based group achieved significantly higher across knowledge, reasoning, and argumentation, both immediately following instruction and 4 weeks later. In addition, unlike the inquiry-based approach, the commonplace science instruction produced a detectable achievement gap by race.

*Reference*

Wilson, C. D., Taylor, J. A., Kowalski, S. M., & Carlson, J. (2010). The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching*, *47*, 276-301.

## *Depth Versus Breadth in Science Education*

*By*: Marc Schwartz, University of Texas, Arlington, TX, USA schwarma@uta.edu

The debate between depth and breath has generated one of the longest, and most contentious, conversations in education. Early in the history of education the trend was to focus on breadth, because the prevailing view was that one person could learn all there was to know about the natural world. More recently, the focus has been on depth of study. This pedagogy has been a more popular point of view for nearly 50 years, and argues that curricula should develop deep understanding because students who cover more material master even less.

Given the strength of current cognitive models of learning, many have accepted the in-depth approach as nearly self-evident, although its implementation in high school science classrooms is often challenging. However, empirical evidence that supports this approach is sparse. A review of numerous bibliographies revealed very few articles of an empirical nature that examine the benefits of either breadth or depth. The few empirical studies that do address the pedagogical choice are unable to build convincing arguments because of competing research goals or methodological limitations. While the dichotomy continues to play a dominant role in how the public and policy makers think about educational goals, the discussion has largely remained "a mile wide," and the empirical basis for any reasoned decision closer to "an inch thick."

The study of Schwartz, Sadler, Sonnert, and Tai (2009) is a first step, but more importantly an empirical step, in evaluating the impact of a teacher's choice of depth versus breadth. We surveyed over 8000 freshmen enrolled in introductory science courses in 55 randomly-chosen universities throughout the United States. The sample was stratified to reflect the relative percentage of students enrolled in small, medium, and large post-secondary institutions.[1] The survey allowed us to examine how the students' experiences in high school science courses were related to their later success in an introductory science course at a post-secondary institution. Specifically, we used a secondary teacher's choice to focus on depth or breadth to model their students' final grades in introductory biology, chemistry, or physics in college.

In terms of choices of depth versus breadth, the trend was consistent across disciplines. Students in any discipline who reported that they had spent 2 or more weeks on a particular topic performed, on average, 1 to 2 points better in their introductory college course (with 10 points equivalent to a letter grade difference). Numerous variables were controlled for, and alternative definitions of depth were used, in establishing the statistical significance of the positive association between depth of study in high school and final grades in the first college science course. To gauge the importance of the 1- to 2-point gain, the authors evaluated the impact of a second year of study in the same discipline in high school. An extra year of study corresponded to a 2- to 4-point improvement in student scores in college, depending on the discipline. Essentially, an investment of 2 or more weeks into in-depth study of one topic during high school science was roughly equivalent to one quarter of a year of additional study in biology, one half a year in chemistry, and nearly two-thirds of a year in physics.

In contrast, the impact of curricula that focused on breadth revealed two surprises. First, we found a negative association across the three disciplines between breadth of study and final grades in college. However, it is important to note that the negative relationship was statistically significant in only one subject, biology. In this case, students in college biology performed as if they had one half year less of preparation. This outcome implies that these college biology students performed as if their high school biology class ended in January (US schools work a September-June academic year). While the findings in regard to breadth, in general, are less compelling because of the limited significance across all three disciplines, it is important to note that we did not find a positive relationship between the choice to focus on breadth and later success in any college science.

Second, we found that breadth and depth were uncorrelated. Students were fairly equally distributed across all four possible combinations of depth and breadth exposure: experiencing neither depth nor breadth, experiencing only depth or only breadth, and experiencing both. This distribution allowed us to more clearly evaluate the impact of pedagogical choices for students and teachers. Interestingly, students in classes where teachers use both pedagogical strategies did not perform better or worse than average in college. There appears to be no positive impact from combining the pedagogies (i.e., spending extra time on some topics, but still managing to cover them all). Students earning the highest college science grades had teachers who chose to spend extra time on certain key topics while also eliminating many topics from their courses.

The implication is that educators who are preparing students for the standardized tests that now dominate the K-12 education system in the United States face a dilemma. These tests are used every 3 to 4 years to measure student, teacher, and school success. The same issue of how to prepare students for future success also extends to the standardized tests that graduating high school students take for admission purposes at post-secondary institutions. While the argument might remain that breadth of study may be appropriate for preparing students to pass tests, we did not find any evidence that this instructional strategy supports students doing better in the same subject in college. We find that while depth of study might not expose students to all the material that they could encounter on a standardized test, this is the only supportable pedagogical focus associated with students performing better in college science. The pressures of performing well on standardized tests are evident. However, doing well in introductory college science courses has a far greater impact on the future of students.

*Note*

[1]This data is part of a broader study, Factors Influencing College Science Success (Project FICSS), which was funded by the Interagency Educational Research Initiative of the NSF, NIH, and USEd (Grant No. NSF-REC 0115649). See http://www.cfa.harvard.edu/smg/ficss/ficss.html .

*Reference*

Schwartz, M. S., Sadler, P. M., Sonnert, G., & Tai, R. (2009). Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework. *Science Education*, *93*(5), 798-826.

# Readers' Forum

## *How Scientists Work*

Which of the following best describes how scientists do their work?

A. Scientists just try out different things until something works.
B. There is a definite set of steps, called the scientific method, which all scientists follow.
C. Scientists use different methods, depending on the question.
D. Scientists use different methods, but they all involve doing experiments.

This item reflects a formative assessment probe suggested by Keeley (2010). While the author regards Choice C to be the preferred one, and I appreciate the point she is aiming to make, I also found myself wondering if the article is perhaps detrimentally devaluing the key role of the scientific method in science. Seeking a second opinion from a prominent scholar in the field, Anton Lawson replied: "Wow!!! That is a tough one. I would be inclined to go with the one-method response [Choice B] . . . What a mess we have [in this area of the nature of science]" (personal communication, November 17, 2010). Now, when an experienced science educator (and presumably a reviewer or two) and a distinguished professor of science education cannot readily agree on the answer to a question published in a journal that targets primary school teachers, I think it is fair to conclude that we have an issue worthy of further consideration.

The scientific method, also referred to as the hypothetico-deductive (HD) approach, comprises the steps of making a puzzling observation, asking a causal question, advancing a hypothesis, generating a prediction from the hypothesis, designing a test to check on the prediction, and comparing the results of the test with the prediction from the hypothesis to draw a conclusion. A more detailed description of the scientific method, together with support for the claims that I am about to make, may be found in Eastwell (2010) and the references it contains.

Science is about developing explanations for natural phenomena, as evidenced by the fact that a scientific theory--a set of statements attempting to explain a broad class of related phenomena--is considered to be the pinnacle of the scientific endeavour. What is more, it is the scientific method that provides the mechanism for developing explanations, including testing them, and it is indeed the method that is used, or should be used, by scientists in conducting and reporting many investigations; namely, those investigations that seek to answer causal questions.

However, the scientific method is misunderstood and being taught, and used, inappropriately in many classrooms. In particular, attempts are being made to apply it to the investigation of all scientific questions, both causal and non-causal, when in fact it applies to the former only. Non-causal questions drive descriptive science, which is characterized by investigations that don't involve explanations/hypotheses. Descriptive studies certainly have a role in science, but they can also be viewed as contributing to parts of the HD cycle (e.g., some of the most useful descriptive studies are those that produce puzzling observations in need of investigation using the scientific method). So, if the scientific method is at the core of how science progresses and guides, or should guide, many investigations, the solution to the present confusion is surely not to ignore it, or "throw it out," but rather to acknowledge it and also use it appropriately.

It follows, then, that I find myself disagreeing with the sentiments in: "Fortunately, many of the new instructional materials have discarded the traditional scientific method approach in favor of a broader depiction of the methods of science, including an emphasis on the importance of creativity in designing investigations" (Keeley, 2010, p 30). How can discarding the very core of how science is done, and advances, possibly foster scientific literacy? Also, in relation to the mention of creativity in this quote, let us also not make the mistake of thinking that there is anything automatic, or non-creative, about the use of the scientific method. Even though the steps are definite and sequential, there is no guarantee that someone trying to follow them will produce useful outcomes, a breakthrough, or whatever. Devising both hypotheses and tests of the predictions that follow from them, which are both features of the scientific method, can demand creativity of the highest order, and the effectiveness in doing these things undoubtedly differentiates between exceptional scientists and good ones.

So, it seems to me that the scientific method needs to be not only acknowledged but indeed saluted, but also used appropriately. If so, perhaps the following, with an accepted Choice B, would make a better probe and help prevent the "pendulum swinging too far" the other way:

Which of the following best describes how scientists do their work?

A. Scientists just try out different things until something works.
B. There is a definite set of steps, called the scientific method, which all scientists follow, although it is not necessarily used in every piece of work.
C. There is no such thing as a definite set of steps that guide the work of scientists.
D. Scientists use different methods, but they all involve doing experiments.

*References*

Eastwell, P. H. (2010). The scientific method: Critical yet misunderstood. *The Science Education Review*, *9*, 8-12.
Keeley, P. (2010). "Doing" science. *Science and Children*, *48*(1), 28-30.

*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!

### *Audience Response System*

***In what ways are you presently using, or planning to use, an audience response system (i.e., "clickers")? Also, in what ways would you like to be able to use an audience response system?***

My use of clickers involves peer instruction (described in Lasry, 2008). I use TurningPoint RF clickers (Turning Technologies, 2010), which provide for multiple-choice questions with up to 10 choices.

*References*

Lasry, N. (2008). Implementing peer instruction in pre-university courses: Clickers in classrooms? *The Science Education Review*, *7*, 21-23.
Turning Technologies. (2010). *Turning technologies*. Retrieved from http://www.turningtechnologies.com/ .

*Nathaniel Lasry, Harvard University, Cambridge, MA, USA*

I have been using clickers, for more than 10 years, in large (250+ students) and small (20+ students) undergraduate physics classrooms:

1. to gauge student understanding of new concepts discussed in class. I usually use 4-5 clicker questions each 1-hour session. I prepare them in advance by inserting them into the PowerPoint presentation. Then I ask a question, let the students think for themselves, and after a minute ask them to vote (individually). After the responses are displayed to the class, I decide how to proceed. If most of the students got it right, we summarize the question and proceed. However, when I see that the students are confused, I ask them to discuss the question with their neighbours (groups of 2-3 students) and then we vote again. The second vote is summarized and we proceed. Very often I ask the students to justify the correct answer, as well as explain what might be the cause of the incorrect answer. Good clicker questions often generate excellent discussions. All the responses are saved and I use them for research, teaching, etc.
2. to administer reading quizzes at the beginning of the class. To make sure the students came prepared to class, I often ask 2-3 short clicker questions at the beginning of the class.
3. to administer multiple choice quizzes and exams. Our system allows us to administer a self-paced assessment; tests, quizzes, etc.

We use *e*Instruction clickers (eInstruction Corporation, n.d.). In my classes, every student own his or her own clicker. They use the same clicker for all science disciplines. Every clicker is registered to the student and the students get credit for using them. When they answer a question correctly they get 2 points, when they answer incorrectly they get 1 point, and when they don't answer, they get no points. At the end of the course, these responses amount to 5% of their final grade. Since we respond to difficult questions twice, and the first response is overwritten, the final clicker grade amounts to 85+%. Their clicker mark is therefore a participation bonus.

In addition, I use conceptual questions, similar to the ones I ask during the clicker sessions, in final assessment. Thus the students know that conceptual questions matter. You can read more about this in Milner-Bolotin (2004). Other papers describing how we use clickers are Milner-Bolotin (2004), Milner-Bolotin, Antimirova, and Petrov (in press), Milner-Bolotin, Kotlicki, and Rieger (2007), and Milner-Bolotin and Moll (2008). Free, environmentally-oriented clicker questions that we have created are available from Milner-Bolotin, Ives, and Stewart (n.d.). Finally, excellent clicker resources are available from Carl Weiman Science Education Initiative at the University of British Columbia (2009).

*References*

Carl Wieman Science Education Initiative at the University of British Columbia. (2009). *Clicker resources*. Retrieved from http://www.cwsei.ubc.ca/resources/clickers.htm .

eInstruction Corporation. (n.d.). e*Instruction*. Retrieved from http://www.einstruction.com/ .

Milner-Bolotin, M. (2004). Tips for using a peer response system in the large introductory physics classroom. *The Physics Teacher*, *42*, 47-48.

Milner-Bolotin, M., Antimirova, T., & Petrov, A. (in press). Clickers beyond the first year: Interactive teaching in upper level physics courses. *Journal of College Science Teaching*.

Milner-Bolotin, M., Ives, J., & Stewart, J. (n.d.). Environmentally oriented clicker questions. Retrieved from http://www.skylight.science.ubc.ca/node/437 .

Milner-Bolotin, M., Kotlicki, A., & Rieger, G. (2007). Can students learn from lecture demonstrations? The role and place of interactive lecture experiments in large introductory science courses. *Journal of College Science Teaching*, *36*(4), 45-49.

Milner-Bolotin, M., & Moll, R. F. (2008). Physics exams reconsidered: Using Logger Pro technology to evaluate student understanding of physics. *The Physics Teacher*, *46*, 410-416.

*Marina Milner-Bolotin, University of British Columbia, Vancouver, BC, Canada*

At the University of Colorado at Boulder (Physics Dept.), we use a modified form of the Peer Instruction method that was popularized by Mazur (1997). In Mazur's method, he asks a challenging conceptual question and has students vote individually. He doesn't show the results, but asks students to talk to their neighbors to convince each other of their answer. Then he has them re-vote. Finally, there is a class discussion on the question.

We use the same method, but generally don't have students vote on their own first, mostly because we find that the important learning phase is during the peer discussion, so we want to allow ample time for that. We are careful not to show the histogram of student responses too soon, since as soon as students know (or think they know) what the answer is, they stop thinking about the question. Often we'll have an entire class discussion, discussing all answer choices, including why the wrong answers are wrong as well as why the right answer is right, before showing the histogram. Sometimes, we'll also use the clickers to have students predict the outcome of a class demo, or answer questions about a simulation we are showing in class.

*Reference*

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

*Stephanie Chasteen, University of Colorado at Boulder, Boulder, Colorado, USA*

I would really like to have an open "stoplight" clicker. When I am giving a lecture segment, I would like to have a clicker recording open so that students could click for "I'm following," "I'm a bit confused," and "I'm totally lost." The circle would change to a pie chart in green, yellow, and red, showing the proportion of students in the three categories. I've actually been told that I might be able to do this with my present TurningPoint clickers, and I plan to try it this fall.

*Edward Redish, University of Maryland, College Park, MD, USA*

Most of the following uses for clickers come from Beatty and Gerace (2009).

- Use as a sign-in to check the roll.
- Elicit students' prior knowledge, thoughts, and/or beliefs.
- Use the free-text mechanism to collect questions that students have about a topic before beginning to study the topic.
- Ask an interesting and/or provocative question to engage students.
- Stimulate discussion with highly disputable questions.
- Induce cognitive conflict.
- Use to elicit misconceptions.
- Use to predict the outcomes of demonstrations and/or investigations.
- Poll students to determine their degrees of confidence in their understanding of a topic.
- Have students "raise their hands" electronically, with the order in which they raised their hands being displayed on a class name list, thus allowing students to be helped in the same order as they raised their hands.
- Build confidence by asking a question that most can answer correctly now, but could not have previously.
- Test for student understanding.
- Use as an exit poll to determine which concepts students most want to spend more time on.
- Collect other feedback at the end of a session.

*Reference*

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology*, *18*, 146-162.

*Peter Eastwell, Science Time Education, Queensland, Australia*

# Laboratory Safety Guidelines

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

### #12 of 40. *Forbid Working Alone in any Laboratory and Working Without Prior Knowledge of a Staff Member*

Working alone is a bad idea. It's an open invitation to tragedy. The legal consequences can be equally serious. For students at the secondary level and undergraduates in teaching laboratories, this means constant adult supervision. It means that only previously-approved experiments are performed. For graduate students, post doctoral fellows, and science faculty, it means that there is always a second person, available to provide immediate assistance in the event of an emergency. This second person should be knowledgeable about the work being performed and capable of rendering assistance if necessary.

Experimental procedures should be reviewed by science faculty prior to their use. This practice helps to insure that significant hazards are identified before the experiments are performed. It was a standard operating procedure in the Dow Chemical New England Research Laboratory and makes very good sense for all research programs.

The legal consequences of allowing students to work alone, or without proper adult supervision, are significant. Since all the professional associations (NSTA, ACS, NSC, NAS, NRC, etc.) clearly state that this is an unacceptable practice, you would be hard-pressed to win a law suit if a serious injury occurred. A smart plaintiff's attorney would point to these professional standards and show the defendant's conduct to be wanting.

Forcing a person to assume an unnecessary risk can result in a claim of malfeasance if there is an injury caused by the act or inaction. The National Safety Council's (1121 Spring Lake Drive, Itasca, IL 60143-3201) Research and Development Section has published (June '87) a safety and health information sheet titled *Off-Hours Laboratory Work.*

In the real world, it would be presumptuous to expect that all working alone is going to end. I'm a big fan of the Jiminy Cricket School of Optimism (when you wish upon a star . . . etc.). However, in the meantime, what can we do to minimize the risk? How about a $50 pair of walkie talkies to provide a sound link between two people in different locations? How about a $30 per month service that provides a button you can press to get help in an emergency? You know: “Help. I've fallen down and can't get up.”

# Further Useful Resources

***GENIQUEST*** (http://www.concord.org/projects/geniquest) This project explores the effectiveness of using a digital model-based genetics environment to support secondary school students in learning the concepts underlying cutting-edge bioinformatics research.

***The Electromagnetic Spectrum Song by Emerson and Wong Yann*** (http://www.youtube.com/watch?v=bjOGNVH3D4Y) A catchy tune that tends to get stuck in one's head.

***PhET Interactive Simulations*** (http://phet.colorado.edu) Fun, interactive, research-based simulations of physical phenomena from the PhET project at the University of Colorado.

***Brainiac – Electric Fence*** (http://www.youtube.com/watch?v=-n1pSHzdahc) Learn about electricity in a fun way. At certain places, stop the video and ask students to discuss and/or make a prediction before proceeding.

***Save the Penguins*** (http://www.uky.edu/~csc222/ETK/SaveThePenguinsETK.pdf) An engineering, design-based curriculum during which students learn how engineers are addressing global warming by designing energy-efficient building materials. Daily lesson plans are included.

# The Benefits of Using Authentic Inquiry Within Biotechnology Education

Nikki Hanegan[1] and Amber Bigler[2]
[1]*The University of Texas at Dallas, Dallas, TX, USA*
[2]*Brigham Young University, Provo, UT, USA*
nikki.hanegan@utdallas.edu

***Abstract***

A broad continuum exists to describe the structure of inquiry lessons (Hanegan, Friden, & Nelson, 2009). Most teachers have heard inquiry described from a range of simple questioning to completely student-designed scientific studies (Chinn & Malhotra, 2002). Biotechnology education often uses a variety of inquiries from cookbook laboratory investigations to authentic inquiries. We examined how authentic inquiry, in the form of student-designed original scientific research projects, impacted learning. In this paper we also describe how students expressed that authentic inquiry in biotechnology education enhanced their understanding. (This paper is a summary of Hanegan & Bigler, 2009)

Advanced biotechnology is the driving force behind innovation in agriculture, drug manufacturing, health services, and sustainable ecology. These industries are rapidly increasing more than twice the average for all industries globally. Zeller (1994) explains that this increase has placed a demand on pre-college teachers to improve biotechnology education to allow students to engage in the increasing workforce needed for new innovations. Additionally, strong recommendations by the National Research Council (NRC) encourage teachers to employ inquiry teaching to increase scientific literacy (NRC, 1996; National Science Teachers Association [NSTA], 2003). Given the societal demands and recurring recommendations, we would expect to see an increase of the integration of biotechnology and inquiry teaching at all levels of education.

However, in a preliminary study we found that biotechnology is most often taught only in advanced biology courses rather than the mainstream courses that most students are required to complete. We also discerned that of 42 biotechnology teachers surveyed, not one teacher incorporated inquiry in their curriculum (Mansius & Hanegan, 2008). Most teachers stated that the equipment did not allow for "authentic" scientific investigations with students. A study conducted by Saye (1997) also stated that students preferred using technology to support teacher-centered instruction.

Although authentic inquiries provide the best learning opportunities, cookbook labs are most often employed in the classroom (Crawford, 2000). Historically, Dewey (1964) exclaimed, "science has too often been taught as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed" (p. 183). We also believe that students should have opportunities to engage in authentic investigations by planning, conducting, redesigning, and resolving their own original scientific studies to draw conclusions within their mandated biology courses.

In order to document learning advantages using authentic inquiries in biotechnology, we conducted this study in hopes that more biology teachers would be encouraged to employ authentic inquiry strategies. Students in this study explored numerous ideas to develop their own scientific research questions in biology using biotechnology equipment and corresponding processes such as DNA extraction, PCR, and bioinformatics. The students were pre-service biology education students interested in the process of learning in biology. All participants had minimal knowledge of biotechnology or its uses in industry.

### *Definitions Used in This Study*

*Authentic inquiry*: Student-driven activity that resembles scientific processes while solving original creative works.
*Biotechnology*: Limited to gel electrophoresis, polymerase chain reaction (PCR), DNA sequencing, and bioinformatic software.
*Intended learning*: Procedural and application knowledge of gel electrophoresis, polymerase chain reaction (PCR), DNA sequencing, and bioinformatic software.
*Unexpected learning*: Extraneous knowledge not taught directly but gained as a result of authentic inquiry participation.

## Study Overview and Data Collection

We invited 5 female pre-service teaching students to participate in this study (known as Alpha, Beta, Gamma, Kappa, and Omega). The researcher did not know any of the student participants prior to the study. Students were asked to complete a series of interviews and two laboratory investigations. The final laboratory investigation was an authentic inquiry activity designed by each student. To avoid possible contamination, the students were asked not to discuss their participation with anyone. The students who participated in this study were never engaged as a group.

We collected data, including video and voice recorded data, from individual students participating in this study for 5 months through weekly face-to-face contact. We also collected emails and phone communications between the researcher and the students.

We collected the data in five phases. Phase I was a baseline interview to determine the initial knowledge level of each student. Phase II was an independent student laboratory experience mimicking the typical cookbook lab most often used in high school settings. Phase III was an interim interview to determine knowledge gains by the students after the cookbook lab. Phase IV was an authentic investigation conducted by the student determined by their own personal interests. Phase V was a final interview to determine the students' final knowledge gains.

Interviews included three basic questions: 1) What do you know about gel electrophoresis? 2) What do you know about PCR? and 3) What do you know about DNA sequencing? All the data was transcribed, categorized, and coded using qualitative software tools. We categorized and tallied the students' responses as either explaining 1) purpose, 2) procedure, 3) application, or 4) understanding. We defined these categories as follows: purpose (identification or factual statement regarding the technology), procedure (statements regarding steps of the protocols for the equipment), application (statements regarding specific identification of what the equipment was used for), and understanding (explanation or elaborations on why, or how, the technology could be used). We then sorted the coded data to determine patterns of information expressed by all the participants.

## Findings

The common pattern we found when we combined all the participants' responses was that authentic inquiry increased student knowledge. Data revealed that students' participation in the authentic inquiry activity of the study, Phase IV, resulted in 1) deepened intended learning and 2) occurrence of unexpected learning.

Tallies or frequencies (*f)* of comments by categories indicated that all five participants increased their knowledge as indicated from a comparison between baseline, *b* (*bf* = 70) and final interviews (*aif* = 212) conducted after their participation in the authentic inquiry activity, *ai*. The greatest gains were found in all areas of procedural knowledge *(bf =21; aif =101)*, followed by the areas of understanding of PCR (*bf* = 0; *aif* = 13) and understanding of gel electrophoresis (*bf* = 6; *aif* = 12). While students showed a significant increase in procedural knowledge about DNA sequencing (*aif = 21)*, they did not indicate an increased knowledge of understanding about DNA sequencing (*aif* = 5). This finding indicated most of the students were better able to express the procedures of gel electrophoresis and PCR equipment usage after the cookbook lab without a significant difference in understanding. However, after the authentic inquiry activity they deepened their understanding of their procedural knowledge.

We also examined the quality of the responses the students provided. Students provided more factual statements after the cookbook lab, Phase II. However, the students expressed more in-depth understanding in their interviews after the authentic inquiry activity, Phase IV. The following comments by Kappa, Omega, and Beta describe this progression of knowledge.

*Kappa Described her Increase in Knowledge About PCR*:

*Baseline interview*. "It's a process used to make a whole bunch of copies of a segment of DNA."

*Interview following cookbook lab*. "PCR is a process where a DNA sample that's too small is going to be put into different machines, and there is a certain protocol that's made for each kind of gene you want replicated."

*Interview following authentic inquiry activity*. "It's used to make copies of DNA, to amplify many, many copies of a certain segment of DNA usually. Primers are used to locate exactly on the template strand, [the DNA extracted], where to begin the amplification. You use catalysts to speed up the reactions, and temperatures at specific times during the amplification for the right environment. And this is repeated many, many times. Just to make more copies!"

B*etween the first lab and the second lab*. "When I first started I just felt like I was following steps . . . [after the second lab] . . . I felt more confident in what I was doing and why I was doing the steps that I was doing. I knew exactly why I was putting the primers in, what they did, and what the taq was used for. I knew I had to set a certain number of cycles, and why they had to be a different temperature and different durations."

*Omega and Beta Described Their Increased Cognitive Engagement as a Result of the Authentic Inquiry Activity*:

*Omega*. "Doing the protocol on my own, coming up with my own question, figuring out how I wanted to answer it, and how I could answer it, caused me to think and to figure it out. I was actually having to learn things and understand them because I was actually doing it: someone wasn't just giving it to me. I had to think of the logic behind that and try to figure out why it was in that order, and what were the different steps we were supposed to accomplish. It was interesting. I learned a lot from making the protocol and just having the experiment on my shoulders. I was responsible for my own learning."

*Beta*. "After designing my own protocol, I had to really understand what was going on to write it. As I was writing it and thinking about things with the gene that I was working with, I think that helped me understand so much more of what I was doing and why I was doing it opposed to just reading a protocol or procedure and just going through it and being like, 'ok, here is the product' . . . I knew what I was working towards ultimately."

## Conclusions

The significance of this study was that the majority of participant learning occurred during the authentic inquiry activity. The frequencies of the comments recorded showed an increase in overall knowledge, and 4 out of 5 students directly reported that they learned most during the authentic inquiry activity. Furthermore, students also reported that they understood more about the nature of science. Students commented on how scientists learn as they discover new knowledge, must articulate their new knowledge so others are able to understand, and that they often need to seek the advice of other scientists as they develop a scientific investigation.

While our study found that students might gain knowledge by doing cookbook labs, the learning is often disconnected and incomplete. All participants commented on the lack of motivation or reason to learn, and the inability to make greater connections during the cookbook lab. Students did not originally realize the differences until they were engaged in an authentic inquiry activity. Our study strongly suggests that students need to conduct authentic inquiry activities for deeper understanding of biotechnology processes and world-wide applications.

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# The Unusual Colour of Copper Deposited on a Graphite Electrode in an Aqueous Solution of $CuSO_4$

Vladimir M. Petruševski and Marina Stojanovska
*Ss Cyril & Methodius University, Skopje, Republic of Macedonia*
vladop@pmf.ukim.mk

***Abstract***

The colour of the copper layer deposited on a graphite electrode during electrolysis of an aqueous solution of copper(II) sulfate looks whitish-grey when inspected in situ. Taking the electrode out of the solution reveals the familiar orange-red colour of deposited copper. The explanation is found in terms of the almost ideal complementary colours of the copper metal (orange red) and the copper(II) sulfate solution (bluish-cyan).

Electrolysis can be defined as a process of chemical change occurring on the electrodes in a solution (or in a melt) as a result of a direct current between the electrodes. The changes are simply the reactions of reduction (on the cathode, the negatively charged electrode) and oxidation (on the anode, the positively charged electrode).

Examples of electrolysis may be found in Fowles (1959), Roesky and Möckel (1996), Shakhashiri (1992), and Summerlin, Borgford, and Ealy (1987). Many more can be found on the World Wide Web. One of the most familiar, and also least expensive, demonstrations of this phenomenon is the electrolysis of an aqueous solution of copper(II) sulfate. Simply place two graphite electrodes in a solution of, say, 1 mol/L $CuSO_4$(aq), connect the electrodes to the poles of a source of direct current (≈ 5-15 V), and inspect the electrodes after several minutes. The electrode connected to the negative pole (the cathode) is covered with a layer of elemental copper that can be recognized by its characteristic orange-red colour. No visible changes to the anode are detected.

One of us (VMP) has performed this demonstration dozens of times over several decades. However, if it was not for students recently noticing something odd, the phenomenon being reported and analysed here would have probably remained unnoticed.

## The Demonstration

Unlike on other occasions when we perform this demonstration for more-experienced university students, this time we guided the discussion with a class of 7 high school students. The electrolysis was performed in a U-tube (Figure 1). We first elicited students' expectations, to find that they predicted correctly that copper metal would deposit on the cathode. The switch was then turned on.

After 3-4 minutes, one of the students asked about the nature of the grey deposit on the cathode tip. Indeed, the graphite electrode tip did look grey, as shown in Figure 2. After about a further 5 minutes, the process was stopped and the electrodes were removed from the solution to reveal the characteristic, well-known colour of copper on the cathode (Figure 3). We now had an observation that needed to be explained: Why does the deposit look grey when the electrode is in the solution? It turned out that the explanation for the seemingly unusual phenomenon was simple and straightforward.

## The Explanation

By chance, it happens that both colours (i.e., that of the elemental copper layer on the cathode and that of the solution) are very close to a pair of complementary colours (Wikipedia, 2010). These colours can be simulated on a computer screen by a pair of truly complementary colours, as shown in Figure 4. The RGB attributes[1] of the blue-cyan colour are 0 (R), 155 (G), and 255 (B). Those of the orange-red one were chosen to be equal to their complements; that is, 255 (R), 100 (G), and 0 (B).

*Figure 1*. The setup for the electrolysis of $CuSO_4$(aq).

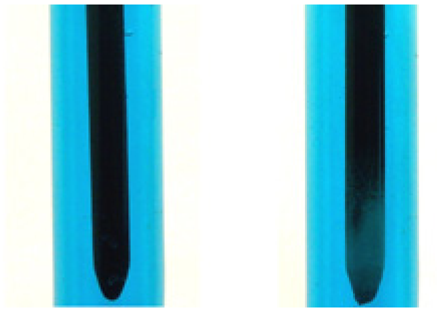

*Figure 2*. The graphite cathode in the $CuSO_4$(aq) solution before (left) and after (right) passing the current. A whitish-grey cover is noticeable on the lower part of the electrode (right).

*Figure 3*. The graphite anode (left) and cathode (right) after being taken out of the solution.

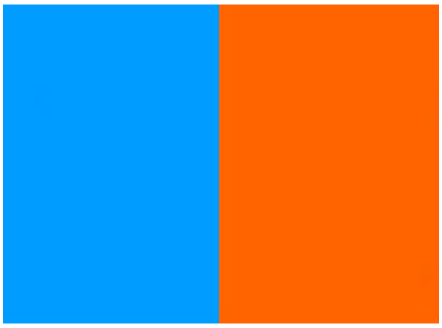

*Figure 4*. A simulated pair of complementary, blue-orange colours.

If the colours in Figure 4 were from two light sources, their combined effect would be white light, which is readily confirmed by the fact that the sum of their attributes equals 255, 255, 255 (i.e., white colour). However, both the solution and the metallic copper layer on the graphite tip are absorbing media. If they were ideal absorbers, they would mutually absorb the light of their complementary colour (i.e., the one emitted by the other medium). In short, in the case of ideal absorbers, one would not notice any change on the graphite electrode while in solution because it is already black.

However, ideal absorbers do not exist. As a result, one sees the copper layer as a grey colour. This is due to the combined effect of the complementary colours of the partly absorbing $CuSO_4$ aqueous solution and the partly absorbing copper layer. Of course, once removed from the solution, the copper layer reveals its true colour (Figure 3).

As with all "big truths," this one is also based on a fairly simple explanation. The amazing part is that it went unnoticed for several decades, only because the instructor knew too well what the result is supposed to be and, despite all his accumulated experience, appeared to be "blind" (i.e., did not pay attention) to the grey layer on the graphite.

## Additional Demonstrations and Checks

One could experiment with viewing Figure 4 through blue and orange light filters. For example, when using a blue filter, there is virtually no difference between the blue and white background, while the orange looks practically black, and we thank reviewer Kevin Carlton for pointing to this additional activity. Also, it could be worthwhile, after the electrolysis activity has been completed but before offering any explanation, to place a copper rod in the solution, to point to its whitish-grey colour, and to ask the students to explain what happened to the copper. In case they think it has reacted with the solution, take it out of the solution, show that it still has its usual colour, and put it back in the liquid. We thank reviewer Wilfred Sugumar for this suggestion.

### *Note*

[1]In *Photoshop*, as well as in many other computer programs, the RGB attributes are determined by 24 bits; 8 bits for each of the elementary colours (i.e., Red, Green, and Blue). Therefore, each colour may vary in intensity from 0 (minimum) to 255 (maximum). There are altogether more than 16 million combinations, ranging from black (0,0,0) to white (255,255,255). The attributes of any pixel can be read, returning a triplet value of the form (R,G,B), where R, G, and B $\in$ [0, 255].

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# "Can we do That Again?" Engaging Learners and Developing Beyond the "Wow" Factor in Science

Chris Astall[1] and Warren Bruce[2]

[1]*College of Education, University of Canterbury, Christchurch, New Zealand*
[2] *UC Education* Plus, *University of Canterbury, Christchurch, New Zealand*
chris.astall@canterbury.ac.nz

***Abstract***

Adding Mentos to an open bottle of Diet Coke can produce a fountain of liquid and froth extending several metres high. This activity can engage a wide audience of learners in a relevant and meaningful way, provide a model for creative science teaching, and help to develop learners' attitudes towards school science as a subject. In this paper, the authors describe the use of this activity with primary-aged learners. Some challenges associated with the construction of the delivery mechanism for the Mentos are discussed, and ideas are provided for improving the performance of the fountain.

An activity that provides an unexpected or startling outcome is usually guaranteed to generate interest, excitement, and enthusiasm from learners of any age. Teachers often look to activities that not only inspire learners but also develop curiosity. The Mentos and Diet Coke activity is one such activity that has been made much more accessible to a wider audience through the Mythbusters television programme (Savage & Hyneman, 2006) and the science educator Steve Spangler (Steve Spangler Science, 2010a). Fritz Grobe and Stephen Voltz, the creators of EepyBird, have taken the Mentos and Diet Coke activity and developed new and unusual ways of presenting the activity through performance art, and their 2006 video, *The Extreme Diet Coke & Mentos Experiments* (EepyBird.com, n.d.), has been watched by millions. The popularity of the Mentos and Diet Coke activity has led to thousands of creative home videos being uploaded onto YouTube.

The Mentos and Diet Coke activity has been successfully used by teachers to demonstrate science processes involved in completing an open-ended physics experiment with undergraduate physics students (Coffey, 2008b). The primary goal was to engage the physics students in "real" research. The students worked collaboratively to explore the different aspects of the activity, including the type of sweets used, temperature of the soda, and ingredients in the sweets and soda. The results from the work of these undergraduates were then published in Coffey (2008a). The interest in the Mentos and Coke activity resulted in the students' findings being reported in the popular science magazine *New Scientist* (Muir, 2008). This activity has also been used within undergraduate Chemistry courses to create curiosity and engagement with an authentic science focus (Baur, Baur, & Franz, 2006; De Grys, 2007; Eichler, Patrick, Harmon, & Coonce, 2007; Liljeholm, 2009; McGuyer, Broen, & Dang, 2009) and also as a model for volcanology investigations (Quane, Klos, & Jacobsen, 2009; Wright, Rust, & Cashman, 2006). Howarth and Woollhead (2008) described the use of this activity with younger learners (12- and 13-year-olds) as they modelled the volcano effect during a class on earth science.

## The Mentos and Diet Coke Activity

Adding Mentos to Diet Coke results in a fountain of liquid and froth being ejected from the bottle. The spray can reach several metres high. This effect is a result of a combination of factors. The carbonated Diet Coke is supersaturated with carbon dioxide that is dissolved under pressure. Once the high pressure on the Diet Coke is released, by opening the bottle, it forms an unstable supersaturated solution of carbon dioxide. The carbon dioxide gas immediately starts to come out of solution and appears as small bubbles. Adding Mentos, with their rough pitted surface, causes rapid increase in carbon dioxide bubbles at the site of the pits (nucleation sites). These nucleation sites, coupled with the coating of gum Arabic, result in the very rapid accumulation of carbon dioxide bubbles within the liquid (Becker, 2007; Coffey, 2008a; Savage & Hyneman, 2006). The result is a violent, explosive fountain of Diet Coke. Coffey (2008a) explored a number of variables that could affect the rapid formation of carbon dioxide; the ingredients in the Mentos and soda drink, roughness of the Mentos, temperature of the soda drink, and duration of the fountain. The addition of potassium benzoate and aspartame in the Diet Coke made it easier for carbon dioxide bubbles to form within the liquid. The faster the Mentos fell through the Diet Coke, the more pronounced the effect. This was because, as the carbon dioxide bubbles rose up through the liquid, they themselves acted as growth sites causing even more carbon dioxide to come out of solution and move into the rising bubble. Additionally, Coffey (2008a) reported that increasing the temperature of the Diet Coke resulted in significantly more carbon dioxide being released from solution, resulting in a more explosive effect.

## Developing Science Process Skills

Science process skills are “the skills scientists employ when they do science” (Martin, 2009, p. 75). They are those skills that enable the children to think, work like scientists, and develop conceptual understanding. As Harlen (2006) states, “the way in which the processes are carried out crucially influences the ideas that emerge. It follows that children’s process skills have a key role in developing understanding” (p. 28).

The Mentos and Diet coke activity provides an ideal way to model a scientific investigation. Such a complex phenomenon, with numerous variables, allows teachers to model a realistic investigation that has relevance to the students. The development of the framework for the experimental design and the data collection and analysis has been described in detail elsewhere for undergraduate students (Coffey, 2008b; Eichler et al., 2007). We were interested in exploring how this activity can be used to help develop the process skills of primary children. These are the key skills that are required by learners as they develop their scientific understanding, and may include hypothesising, observing, questioning, predicting, planning, interpreting, drawing conclusions, and communicating and reflecting (Harlen, 2006; Harlen & Qualter, 2009; Martin, 2009).

In the recently-revised New Zealand Curriculum (NZC) (Ministry of Education, 2007), these process skills are encompassed in the overarching strand called Nature of Science (NoS), which consists of four aspects: understanding about science, investigating in science, communicating in science, and participation and contribution. NoS is the core strand of science in the NZC and will challenge teachers, as it is intended to be the main focus of learning, with the traditional content providing the contexts for learning (Bolstad & Hipkins, 2008). Our challenge has been to find activities that can be used to model and develop understanding of the NoS strand through contexts that are engaging and motivating for both the learner and the teacher. In this paper, rather than describe the procedure that learners may go through to complete a science investigation based on the Diet Coke and Mentos activity, we will provide an example of how we have chosen to use it to help develop learner understanding of a specific process skill; that of questioning. At the same time, it will be seen how the activity can engage 7- to 13-year-old learners in a relevant and meaningful way, provide a model for creative science teaching, and help to develop learners’ attitudes towards school science as a subject.

## Inquiry Using the Mentos and Diet Coke Activity

A group of 8 children from each of Year 3 (age 8 years), Year 5 (age 10 years), and Year 7 (age 12 years) were chosen at random by their class teachers and each group was asked to participate separately in the activity with the researchers. Each group observed the Mentos and Diet Coke activity. A clear plastic tube containing 11 mint Mentos, prevented from falling by a metal pin (see Figure 1), was screwed onto the top of a 2-L bottle of Diet Coke that had been kept at room temperature. One child from each group pulled the pin from the tube and the children were asked to observe. Following the demonstration, the children shared some questions with each other about what they might wish to investigate or find out about the demonstration. By sharing their questions, the students were able to start developing their own thinking about the science concepts that they could identify. They were beginning to look for reasons that the Diet Coke erupted from the bottle. These questions could then form the foundation for their own science inquiry.

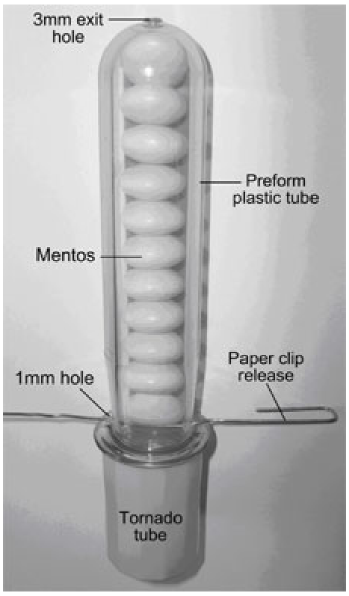


*Figure 1.* The delivery apparatus for the Mentos and Diet Coke activity. The total height of the apparatus is 18cm.

In our experience, many of the questions at this stage are spontaneous, driven by the awe and wonder of the reaction, and are often related to how the phenomenon works. The children ask these questions for a variety of reasons--expressing wonder and interest, wanting to know an answer, and gaining attention--but it is the questions that require complex answers that are more challenging for teachers (Harlen, 2006). We often encountered questions such as the following: “Why does the coke do that?” “Why did the Mentos dissolve into the Coke?” “Why does the Coke react with the Mentos?” “Why is there less coke now [after the ‘reaction’]?” “How did the Mentos make the Coke go up and up and up?”

With each group of children, we then introduced the idea of an investigable question-starter stem as a strategy to turn the more complex type of question into one that can be investigated (Harlen, 1985). We have often found that children have had little experience of asking science questions. Providing children with a question-starter stem results in a richer variety of questions being asked, questions that could then be investigated by the children to help develop their conceptual understanding. Using the question-starter stem “what would happen if…?” each student was asked to share their new question with the rest of the group. The responses from students in each group were as follows:

*Year 3 (8-year-olds)*: "What would happen if:

- there was Mentos in the bottle and you poured coke inside it?"
- you put sugar into the bottle instead?"
- you just put two Mentos into the bottle?"
- you put Mentos into the bottle but the bottle was not standing on a flat surface but on an angle?"
- you put the bottle on its side?"
- You quickly put the Mentos in, put the lid on, and shook it all up?"

*Year 5 (10-year-olds)*: "What would happen if:

- you used a different [size] bottle?"
- you used a different soft drink [soda]?"
- we tried a different lolly [sweet] instead of Mentos?"
- you dropped the Mentos in one-by-one?"
- the top was completely sealed so there was no place for the coke to come out?"
- we used different sorts of Mentos?"
- If you put something on top of the hole [where the Diet Coke comes out ]?"
- added the Mentos and turned the bottle upside down? Would it take off like a rocket?"
- you didn't have that thing [geyser tube] and just left it open and dropped them [Mentos] into the bottle?"

*Year 7 (12-year-olds)*: "What would happen if:

- we tried it with a different lolly [sweet]?"
- we had a bigger bottle [of soda]?"
- we tried only one Mentos?"
- the bottle fell over?"
- we tried it with something else that would fizz up the same as Diet Coke, another liquid like Fanta?"
- we used juice because juice isn't fizzy?"
- there was only half the amount of Diet Coke in the bottle; would it still fizz?"
- we used flat Diet Coke?"
- we added dry ice instead of Mentos; would it do the same thing?"
- you tried baking soda instead of Mentos?"
- you used the stuff to make a volcano--vinegar and baking soda--in the bottle?"
- you used baking soda and vinegar; would it go higher?"
- you didn't have holes in the tube; would it explode?"
- you changed the number of holes?"
- you change where you put the hole?"

It became clear that the responses not only reflected children's previous experiences (e.g., older children have reacted baking soda with vinegar and have seen the fizzing that occurs, and related this fizzing to what they had seen), but also the development of other process skills such as observation and predicting. The younger children placed greater emphasis on their own observations and the previous responses of the other children within the group; a number of times the children repeated the same question or reworded it. We have found that the process of generating questions leads naturally into exploring which of those questions can be investigated, which in turn leads to the identification of those variables that may affect what is observed. The children can choose one of the questions to investigate and then design an experiment to test this question. We have often found that much of the rich discussion comes from challenging the children's experimental designs. In discussing children's learning, Harlen (2006) emphasises that "children's process skills have a key role in developing understanding" (p. 29). The Mentos and Coke activity certainly supports the development of the process skills that are embedded within typical frameworks for science investigations.

The types of questions that children ask can also give teachers greater insight into students' understandings of the science concepts within the activity. Teachers can use this type of formative assessment in their teaching, maybe using this as an opportunity to identify any potential student misconceptions and then providing an opportunity for the students to explore their ideas.

## Inspiring Creativity

In our experience, an activity such as the Mentos and Diet Coke one provided children with a real sense of awe and wonder. They were engaged in the activity and wanted to participate. They showed curiosity, not only about how the process worked, but also about ways in which they could change or develop it, and this often led to a wealth of questions. Children sharing their thinking and questioning aloud appeared to engage the rest of the group so they become more willing to share their own ideas and opinions of what was happening. Oliver (2006) identified that creative science teaching means teachers value speculation and original thinking, allow children to share and generate ideas, and give children time to talk. Encouraging wonder and curiosity and providing challenging activities are also characteristics of creative teaching (Feasey, 2005; Oliver, 2006). However, the activity becomes all the richer if the children are able to explore and test their own ideas. Young learners often think creatively when challenged. For example, when we discussed the children's questions and started to think about how we could test their ideas, we asked the children how they could gather data when they used different drinks or when they used a different number of Mentos. They suggested a number of methods, including some very creative ideas: measuring the height of the coke fountain, placing holes in the side of the release tube and measuring the horizontal distance the fountain travelled, measuring how much liquid was left in each bottle, simply lining the bottles up side by side to form a comparative "bar graph," and measuring the weight of the bottle before and after the reaction.

The children start to then move beyond just the awe and wonder into "doing" science. This type of constructivist learning occurs when the learner is provided with opportunities to build and develop their own conceptual understanding of the science concepts and skills through experience.

## Challenges With Constructing the Apparatus

### *Delivering Mentos Into the Bottle*

In our experience, one of the greatest challenges is to find a way to deliver the Mentos into the bottle of Diet Coke. Placing a number of Mentos (5 or 6) into a rolled tube of paper and then dropping them into the open mouth of a bottle of Diet Coke is effective. However, once started, the effect is so quick that often not all the Mentos have time to drop into the liquid.

Another method is to drill a small hole (about 5-mm diameter) through the cap of a Diet Coke bottle and thread a piece of wire through the cap (EepyBird.com, 2009). A hole is drilled into each of three or four Mentos and they are threaded onto the wire on the bottom side of the cap. This requires pouring a small amount of Diet Coke out of the bottle to allow enough space for the Mentos to hang just above the surface of the liquid. The cap is then screwed back on the bottle, with the wire held in place externally by a spring clip. Releasing the clip causes the wire to fall through the hole in the cap and the Mentos, attached to the wire, to fall to the bottom of the Diet Coke.

Steve Spangler has developed a geyser tube that allows a larger number of Mentos to be delivered into the Diet Coke in a more controlled manner (Steve Spangler Science, 2010b). However, we found there was a loss of liquid from the area where the release mechanism was screwed to the top of the bottle and from the hole at the base of the tube when the release pin was pulled. The commercial mechanism has a collar that drops down when the pin is pulled, but the collar is very loose and it does not stop liquid coming out over the collar.

### *Reducing Soda (Diet Coke) Loss*

We looked for ways to reduce this soda loss by using a 2-L soda bottle preform tube and a tornado tube connector (Tornado Tube, 2008), as shown in Figure 1. A tornado tube connector allows two soda bottles to be joined together without leaking. The hole in the tornado tube connector was enlarged, using a keyhole saw, to allow the Mentos to pass smoothly through the tube into the Coke. The size of the exit hole does have an effect on the distance the soda travels, as well as the duration of the reaction (Coffey, 2008b). Using this apparatus, it is possible to prepare a number of preform tubes with different-diameter exit holes. This is a variable that could be explored further by the learners. However, we have found that a 3-mm hole creates a fountain that lasts longer, and is higher, than those obtained using holes of other diameters.

A 1-mm hole was drilled, through both sides, just above the lip of the inverted preform tube (Figure 1). The preform tube was filled with Mentos and a straightened paper clip was inserted through the 1-mm holes, preventing the Mentos from falling out of the tube. The tube was then screwed tightly onto the tornado tube connector. The “loaded” preform tube was then screwed onto a bottle of soda. To release the Mentos into the soda, the paper clip was pulled from the tube.

However, we still found that a small amount of soda was again lost through the two holes when the paper clip was removed. So, instead of drilling two holes for the paper clip release mechanism, we are now using a small, steel ball-bearing held in place by a strong magnet. The position of the ball bearing prevents the Mentos from falling into the soda. When the magnet is removed, the ball bearing drops into the soda, along with the Mentos. This proves most successful, as there is no loss of Diet Coke from any point other than the 3-mm hole at the top.

## Conclusion

Concerns over the decline in primary-student attitudes towards science has been the subject of recent debate, both in New Zealand and in other countries such as the United Kingdom and Australia (Bolstad & Hipkins, 2008; Crooks & Flockton, 2003; Crooks, Smith, & Flockton, 2007; Milne, 2010; Porter & Parvin, 2008; Tytler, Osborne, Williams, Tytler, & Clarke, 2008). Early engagement in science matters if we are to develop students’ ideas and interest in science (Tytler et al., 2008). The Mentos and Diet Coke activity is a good example of an activity that can be used by teachers to provide a context for students that is meaningful and relevant to them. Such science contexts are important if students are to develop their science process skills (Harlen, 2006). This activity can also provide students with a positive experience of learning science that leads to increasing engagement with, and enthusiasm for, science.

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# Environmental Education in an Age of National Standards and Videophilia


Michael L. Bentley
*University of Tennessee, Knoxville, Tennessee, USA*
mbentle1@utk.edu



***Abstract***

This article is based on the work of Louv (2005, 2008) and Lowell (2008) and their ideas are explored with regard to barriers to, as well as opportunities for, effective environmental education. State curriculum standards in the U.S. include substantial environmental education (EE) content. Despite this, overall education policy stymies educators' efforts in enacting effective classroom programs. While the education policies of every country should be reassessed in light of what scientists are telling us about the "global macroproblem," policy efforts alone will fail unless educators recognize that outdoor experience has to be a key component of a contextualized, place-based EE. Part of a rational response to environmental issues is to educate our children as to their relationship to, dependency upon, and responsibilities to their ecosystems. Addressed are the role of EE in the school curriculum and the value of addressing learners' connections to nature from a personal rather than intellectual viewpoint.


> In the patent-or-perish environment of higher education, we see the death of natural history as the more hands-on disciplines, such as zoology, give way to more theoretical and remunerative microbiology and genetic engineering . . . as the young spend less and less of their lives in natural surroundings, their senses narrow, physiologically and psychologically, and this reduces the richness of human experience. (Louv, 2008, pp. 2-3)

### How EE is Compromised by Standards-Based Reform

In the United States (U.S.), environmental education (EE) has not been a priority in the current era of educational standards and high-stakes testing, testing that has significant consequences for the school or the test taker (e.g., grade retention or type of diploma). Our 50 states developed their individual curriculum frameworks in the 1990s in order to achieve compliance with the national Goals 2000 legislation, requirements in the Elementary and Secondary Education Act, and the No Child Left Behind Act (NCLB) (Council of Chief State School Officers, 1995).

Environment-related content is included in U.S. national standards documents for science (American Association for the Advancement of Science [AAAS], 1993, 2009; National Research Council, 1996), geography (Geography Education Standards Project, 1994), and social studies (National Council for the Social Studies, 1994). For example, in science, standards can be found relating to concepts such as the water cycle, trophic levels and food chains, ecological succession, and natural resources. These national documents, however, were written as guidelines only, but state standards based upon them are mandatory as required by the NCLB Act. Illustrated in Figure 1 is the environment-related content in Virginia's science standards for Grade 3. While this inclusion of EE content has some merit, the work of school-based environmental educators is now prescribed and restricted by whatever content their state documents specify. Standards-based reform has rigidified disciplinary boundaries, thus presenting an obstacle to interdisciplinary environmental education.

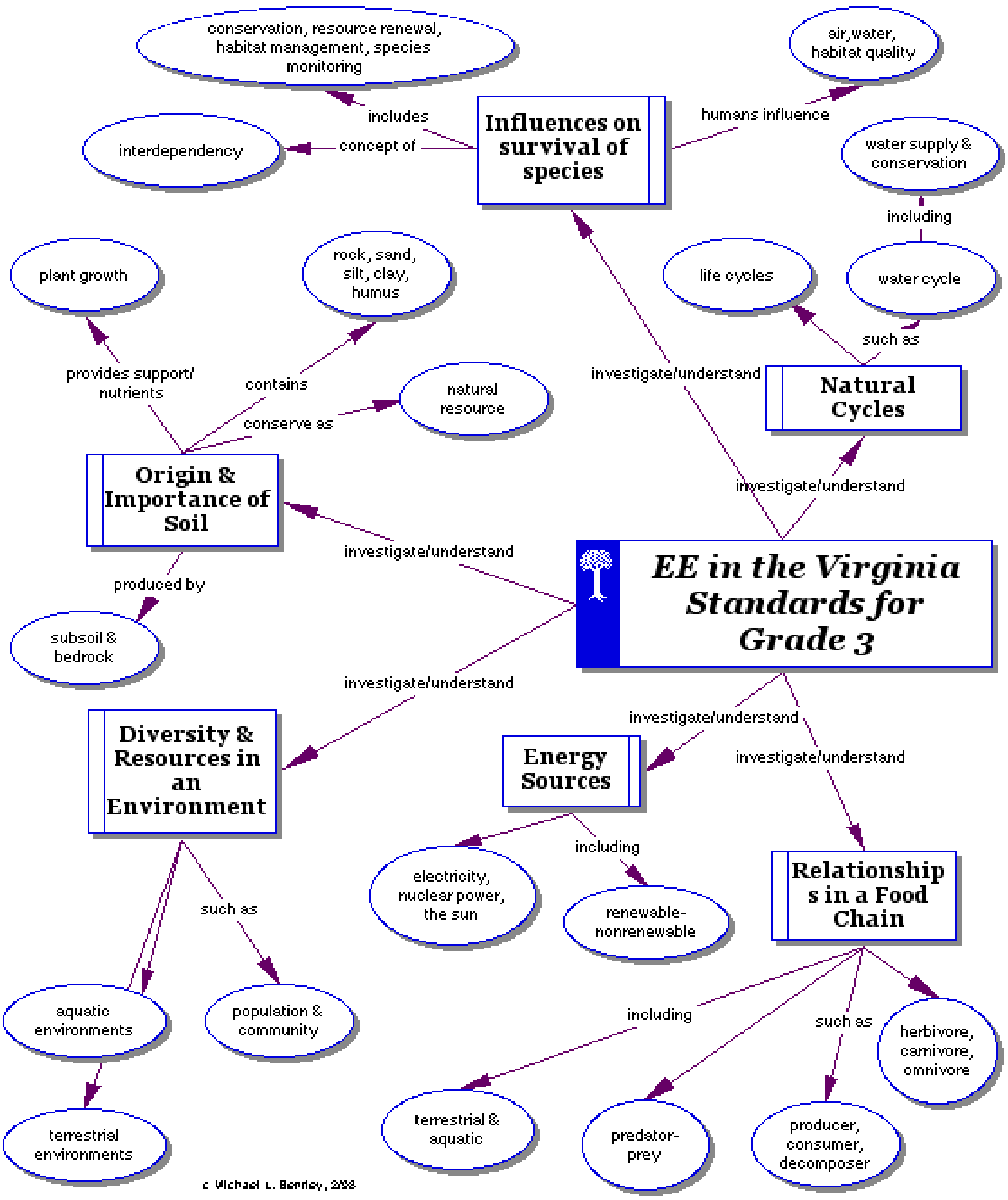


*Figure 1*. An example of environmental content in the Virginia state curriculum standards.

In addition, the implementation of standards-based accountability has been detrimental to EE due to schools placing too much importance on student test scores and annual yearly progress (AYP). This focus has resulted in a shift in teacher-preferred pedagogies and also to a neglect of the affective domain. Teachers have now returned to more didactic methods as more suitable ways for "covering" the large amount of curriculum content prescribed for state tests, and away from indirect or inquiry methods. According to Jones, Jones, and Hargrove (2003), "the negative effects of high-stakes testing on teaching practices can include an unbalanced emphasis on teacher-centered approaches and a reduction in teacher and student creativity" (p. 44). Further, according to Au (2007):

> High-stakes tests encourage curricular alignment to the tests themselves. This alignment tends to take the form of a curricular content narrowing to tested subjects, to the detriment or exclusion of nontested [*sic*] subjects. The findings of this study further suggest that the structure of the knowledge itself is also changed to meet the test-based norms: Content is increasingly taught in isolated pieces and often learned only within the context of the tests themselves. Finally, in tandem with both content contraction and the fragmentation of knowledge, pedagogy is also implicated, as teachers increasingly turn to teacher-centered instruction to cover the breadth of test-required information and procedures. (p. 263)

Affective outcomes such as the development of children's attitudes and motivations and their ethical development in relation to the environment, which would be very important from the perspective of a John Dewey, are typically absent in technicist, standards-based lesson plans. This absence is significant because, as Dennis and Knapp (1997) note, "environmental education includes both cognitive and affective dimensions. . . . [There is a] strong concern for attitudes and motivation" (p. 8). The most effective programs in EE have been found to be those in which "products (test scores) are not emphasized, inquiry is sparked, open-ended questions are generated, and students actively participate and appear involved" (Price & Hein, 1991, p. 510). In its own guidelines, the North American Association for Environmental Education (NAAEE) (2004) includes personal and civic responsibility as one of four strands for EE in the K-12 curriculum. The graphic of Figure 2 illustrates the framework NAAEE suggests for EE. That students should learn about the natural history of their own locales is strongly implied in the framework. Unfortunately, NCLB has not fostered contextualized, place-based EE and has actually shifted teacher's preferred pedagogies in a different direction.

In terms of this shift in pedagogies brought about by standards reforms, teachers have moved away from the use of inquiry strategies and toward more use of direct instruction, and thus there has been a decline in student field studies and experiential learning (Amrein & Berliner, 2002; Blair & Archer, 2001; Brown & Bentley, 2004). This shift in pedagogies may impede other educational purposes, such as the development of student interests, autonomy, and independent thinking. The focus on recalling information in order to raise standardized test scores distracts students from the intellectual substance of the content and transforms "their efforts to learn into efforts to please" (Lantieri, 1995, p. 387).

Standards-based curriculum subtly communicates to the public the curriculum fallacy of universalism. This is the view that some particular content can be identified that is of fundamental and universal significance regardless of context, or of the characteristics of the student. Universalism is the fallacy of believing there is a "best" curriculum (Doll, 1996). The U.S. *National Science Education Standards* commit to this very fallacy in proclaiming that the content identified by the National Research Council (NRC) (1996) must be learned by every student regardless of age, gender, race or ethnic background, disabilities, interests, motivation, or aspirations.

Standards-based reform has fostered the deskilling of teachers by prescribing for them the content they are to enact in their classroom curricula, thus narrowing the decision-making processes within their work (Center for Educational Policy, 2008; U.S. Government Accountability Office, 2009). It has transferred curriculum decision-making from the local level to the state and national levels. The push for conformity and uniformity ignores the importance of both context and diversity in teaching strategies and methods. As state assessments are tied to standards, more "teaching to the test" has resulted, and that in turn has resulted in less attention to teaching higher-level thinking skills. As pointed out in her new book, *The Death and Life of the Great American*

*School System*, educational historian Diane Ravitch (2010) claims that NCLB has led to a mechanistic and anti-intellectual education and that we have lost sight of the goal of education, which is to produce educated people. She argues for the democratic, civic purposes of public schooling and against using tests to make “consequential judgments” (p. 153) about students and schools. As I see it, the purpose of education should emphasize “diversity, creativity, social responsibility, empowerment to think and, more particularly, to act” (DeBoer, 1991, p. 240).

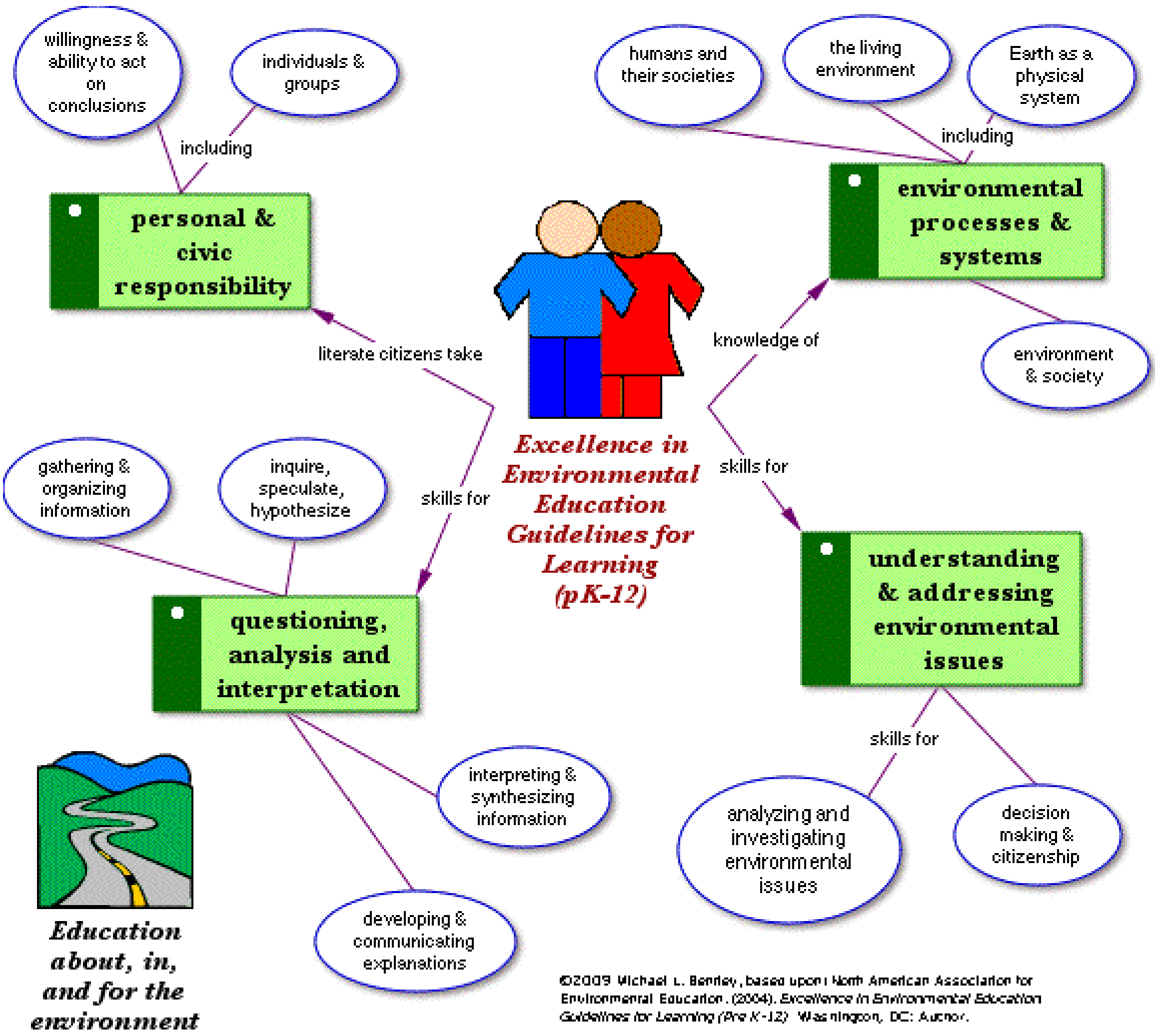


*Figure 2.* An illustration of the strands in the North American Association for Environmental Education (NAAEE) (2004) guidelines.

Epistemologically, the standards-based curriculum is thoroughly modernist, but postmodern thought stands against the metaphysical idea of a universal human nature and features a deeper appreciation of human individuality. David Elkind (1997) points out that “what has come to the fore in postmodern times is the awareness of the importance of difference” (p. 242). As Linda Lantieri (1995) argues:

> The problem is not with standards as such; it is with standards imposed entirely from without - impersonal standards that turn students into objects and disrupt connections between teachers and students and between students and their work. (Effective) teachers . . . have high expectations of their students, but the expectations are constructed in collaboration with the students, and they are translated into ‘informational’ rather than

> ‘controlling’ feedback. Controlling feedback is ‘outcome oriented,’ while informational feedback ‘is focused on the ongoing activity.’ (p. 392)

So, the issue is not with standards per se, as standards certainly did exist before the current reform movement and teachers should have appropriate academic standards; expectations that are recognized alike by student, teacher, and parents. However, standards are properly established at the local level because every child is unique, having his or her own history, personality, learning preferences, gifts and talents, interests, and aspirations. Individual achievement standards are best negotiated between student, parents, and teachers.

### Nature Deficit Disorder Appears as an Upshot of the Digital Revolution

The phenomenon of nature deficit disorder (NDD) was introduced by writer and child advocate Richard Louv in his book, *Last Child in the Woods,* first published in 2005 and expanded in a 2008 edition. Louv writes about the lifestyles of today’s American youth and about how little the experience of nature is part of their lives. He documents what most of us already have observed; that students nowadays are far more focused on their screens than on the out-of-doors. The consequence of this situation, he argues, is the declining health of our population as well as other growing societal ills. He calls the problem nature deficit disorder, which he is careful to point out is not a medical diagnosis. In 2008, the National Audubon Society (n.d.) presented its Audubon Medal to Louv for encouraging more contact between children and the natural environment.

Louv cites a variety of studies to support his argument, many of which document increasing screen time and declining physical activity for U.S. children. The Center for Research on the Influences of Television on Children (CRTIC) at the University of Texas at Austin found that children in America spend more time watching television than in any other waking activity, with additional time devoted to video and computer games and to using the Internet (Vandewater et al., 2005). In fact, U.S. households contain some 250 million TV sets--more than the number of our children (Herr, 2007)--and our children watch more TV than children in any place else in the world.

Clare Lowell (2008) writes of videophilia as the tendency “to focus on sedentary activities involving electronic media” (p. 219) and says this new obsession of our society has “virtually supplanted the need for ‘biophilia,’ or the urge to affiliate with other forms of life” (p. 219). She sites researchers Hofferth and Sandberg (2001) who found that the “proportion of 9- to 12-year-olds who engage in outside activities such as hiking, walking, fishing, beach play, and gardening has declined by 50 percent . . . [and] children’s free play time in a typical week has declined by a total of 9 hours over a 25-year period” (p. 220). The health consequences for such sedentary lifestyles include obesity and a host of diseases such as diabetes, hypertension and heart disease, depression, and cancer, and then there are the social and economic costs of these lifestyle issues (Lorenzo, 2009). The prevalence of obesity in American children has increased dramatically with 1 in 5 children 12 to 19 years old now being overweight (U.S. Department of Health and Human Services, 2009, Table 67).

This situation is to be deplored for more than one reason. For parents, the health consequences for their children alone should raise an alarm. But for a democratic society, this trend could result in a population of citizens less sensitive to environmental issues. Even today many Americans either deny that serious environmental problems exist or discount the necessity of acting to ameliorate them because, for example, it will hurt the economy.

A generation is now growing up less physically active and less connected to nature. Yet natural history, the systematic study of natural objects, phenomena, and organisms, is virtually ignored by the two major reform documents that guided the development of most of the state science standards, *Science for all Americans* (AAAS, 1989) and the *National Science Education Standards* (NRC, 1996). While proposing a substantial body of content related to earth and life science, these documents do not recommend methodical studies of nature by students (Melear & Hagevik, 2007).

Thus we see a decline in the U.S. of contextualized, place-based environmental education. During the school day, the pressure on teachers to cover their state standards increasingly usurps field studies and time outdoors. Many schools have abolished recess above the primary grades (Henley, McBride, Milligan, & Nichols, 2007). Further, many schools now require teachers to justify field studies exclusively in terms of addressing particular standards.

## What is to be Done?

So, what can school-based environmental educators do? For one thing, they are advised to study their state standards to identify the environmental education content therein, as is illustrated for the Grade 3 Virginia science standards (Figure 1). They can also look for compatible and complementary standards in their state's social studies, health and physical education, and other standards documents. Cross-linking standards can be used to justify curriculum integration, one of the strengths of environmental education. Environmental educators will have to fight hard for field-based studies and affective education, but, of course, that is something we have always had to do.

Recognizing the priority of EE and natural history studies as part of the curriculum is only one part of the solution. One of the biggest obstacles educators may face in the classroom is a mindset, or misconception, identified by Daniel Quinn (1996) as the Great Forgetting, an overarching world view or paradigm that "blinds us to the fact that we are a biological species in a community of biological species and are not exempt or exemptible from the forces that shape all life on this planet" (p. 307). The educational implication of Quinn's hypothesis, as I interpret it, is that EE should be infused with a paleontological and archaeological perspective. The historical perspective can be integrated when teaching ecological concepts and principles. This perspective also is compatible with field studies and place-based education. Such EE can help children construct more sophisticated, broader understandings of our species' genetic and pre-historical context. Man: A Course of Study (MACOS), a National Science Foundation (NSF) funded curriculum project of the 1970s, was a course that helped students perceive such a long view.

Finally, those of us who teach in schools should recognize more fully the value of informal environmental education; that is, programs and experiences developed outside the classroom by institutions and organizations that include:

- nature centers and environmental education centers, children's and natural history museums, zoos and aquaria, botanical gardens and arboreta, parks, and scientific research laboratories,
- media (print, film, broadcast, the Internet, and other electronic forms), and
- community-based organizations and projects and youth organizations.

Researchers have documented the significant impact of informal learning experiences on youth. Informal education institutions provide professional development for teachers and enrich the education of students and the public (Coffield, 2000). From my own observations, I have found that schools could do much more to engage with EE resources in their communities. Many agencies employ educators who specialize in interpreting different phenomena and issues to the public using hands-on and engaging experiences (Pranis & Duffin, 2009). Groups like the Sierra Club (2010) often provide natural history interpretations as part of their regular outings.

## Exemplary Practice: Signs of Hope

In education, the public good is not always best served by the government-sponsored schools. In the U.S., unlike in Britain, private schools are exempt from state curriculum standards and testing. One not-for-profit, non-sectarian private school whose curriculum is rich with opportunities for experiential outdoor learning is Community School (CS) (n.d.), located in Roanoke, Virginia. For 40 years, CS has served a diverse population of 150 students from pre-K through middle school. The affiliated Community High School (CHS) (n.d.) was started in 2001 and serves 60 students in Grades 9-12.

Community School's non-traditional educational program features a learner-centered curriculum enacted in non-graded, multi-aged classes with a low pupil-to-teacher ratio. The curriculum is interdisciplinary and includes a strong experiential environmental education and community service component. Fridays each week of the school year are typically devoted to field studies and students are given several choices of trips and activities. Overnight and week-long camping opportunities are offered, with longer stays for the older students. In the spring, middle school students may opt to study environments in more distant places, such as the Florida Everglades National Park and sites in other countries. My own daughter visited tropical forests in Bolivia as part of a student exchange with a Bolivian middle school.

Community High School (CHS) represents a new and unique niche in education: the “museum school.” This concept has emerged only recently with only about 20 examples in the U.S., with these representing a variety of designs. There is no commonly accepted definition of a museum school, but such schools typically involve partnerships with local institutions of informal learning and offer a curriculum with long-term projects that involve students in working with objects, exhibits, or museums. Community High School is charting new territory, particularly in developing the practice of collaborations between a formal school and multiple agencies using real-world learning sites.

In both schools, environmental education is infused in an integrated curriculum that involves outdoor experiential learning. Of course, there are other examples of schools with exemplary EE. The *New York Times* has reported on the Waldorf School of Saratoga Springs, New York, where students spend 3 hours outdoors each day, regardless of the weather (Leyden, 2009). Jane Goodall's Roots & Shoots (n.d.) program, and many of the outdoor schools in California, are other examples of exemplary practice.

Another area where there is a sign of hope is teacher education, which includes professional development for teachers. My colleague Claudia Melear’s worked for many years with graduate students and pre-service science teachers on Ossabaw Island, off the coast of South Carolina. The course (Melear, 2006) involved an extended camping trip to this remote and pristine island. Teaching duties were shared with scientists from the fields of ecology, biology, and other disciplines. During the program, students made extensive collections of specimens, used field guides, and planned environmentally-based lessons for their own future students. Melear’s work in facilitating studies in, and reflection about, the island’s natural setting is an example of the kind of pre-service education and professional development that results in a bonding between teachers and nature and the development of a conservation ethic.

I have directed a number of grant-funded professional development institutes for teachers that have included extensive field studies and emphasized community-connectedness. The most recent of these is the 2009-2010 Hollins University Inquiry, Integration and Differentiation Project, involving an intensive 2-week summer institute for Grades 4-6 teachers and follow-up academic year seminars (Bentley & Godard, 2010). A unique feature of the project, funded by an Improving Teacher Quality grant from the State Council for Higher Education of Virginia, is the partnership with two local museums, a zoo, a wildlife center, a soil and conservation district, and a land-grant university outreach program.

One last example that represents a hopeful development is online parent education. I recommend you explore the enormous bank of accessible resources freely available on the popular Education.com (2010a) website. This online parents' resource currently receives some 1 million visits per month. For Earth Day 2009, I served as editor of a Special Edition for Education.com focusing on nature deficit disorder (NDD) (Education.com, 2010b). The 33 essays in the issue provide information to parents on specific ways they can help their children more richly experience natural environments from rivers and beaches to fields and forests.

As parents become more aware of the value of outdoor experience, new organizations are being created to provide such opportunities. A new organization where I live is Kids in the Valley, Adventuring! (KIVA) (2010). The purpose of the organization is to provide opportunities for children in the Roanoke Valley to get outdoors and explore. The family that started the group received a $1,000 award from Disney and Family Fun Magazine and now hundreds of families participate in the group's hikes and other nature activities.

Finally, one result of Richard Louv's wake-up call is that the No Child Left Inside Act (NCLI) passed the U.S. House of Representatives in 2008. The Senate did not consider the act and thus it has not been enacted into law. However, if the act is brought back, it could provide funding for schools and non-formal environmental education centers, as well as authorize the creation of state environmental literacy plans so that children would have more opportunities to discover their personal connections to the natural world. This act should become law for the simple reason that today's youngsters are tomorrow's leaders. We should not want to be led by people who are alienated from wild environments or ignorant of the value of nature's ecosystem services.

## Conclusion

Standards-based reform, with its high-stakes testing, may eventually fade away, as did management-by-objectives (MBO) and other technicist educational fads, but for the present environmental educators must be pragmatic and make the best of the situation. This modernist curriculum development model devalues the work of the teacher, since, among other things, it is about prescription rather than negotiation and ignores the reality that teaching practices are embedded in the assumptions and professional motivations of the teacher (Bentley, 1998).

This is a time in the history of the world at which we all need to reassess how we live our lives in light of what the scientists are telling us about the global macroproblem; environmental pollution, land degradation, forest and wetlands losses, accelerating species extinctions, resource depletions, and global climate change. Part of a rational response to our current global condition is to better educate our children as to the reality of their connection to, and dependency upon, nature. Our children need to be grounded in reality, rather than in video game fantasy. As Hofferth and Sandberg (2001) note, “conservation will fail unless it is better connected to people, and people start out as children who need to revere their connection to nature from a personal, rather than intellectual, viewpoint” (p. 222).


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