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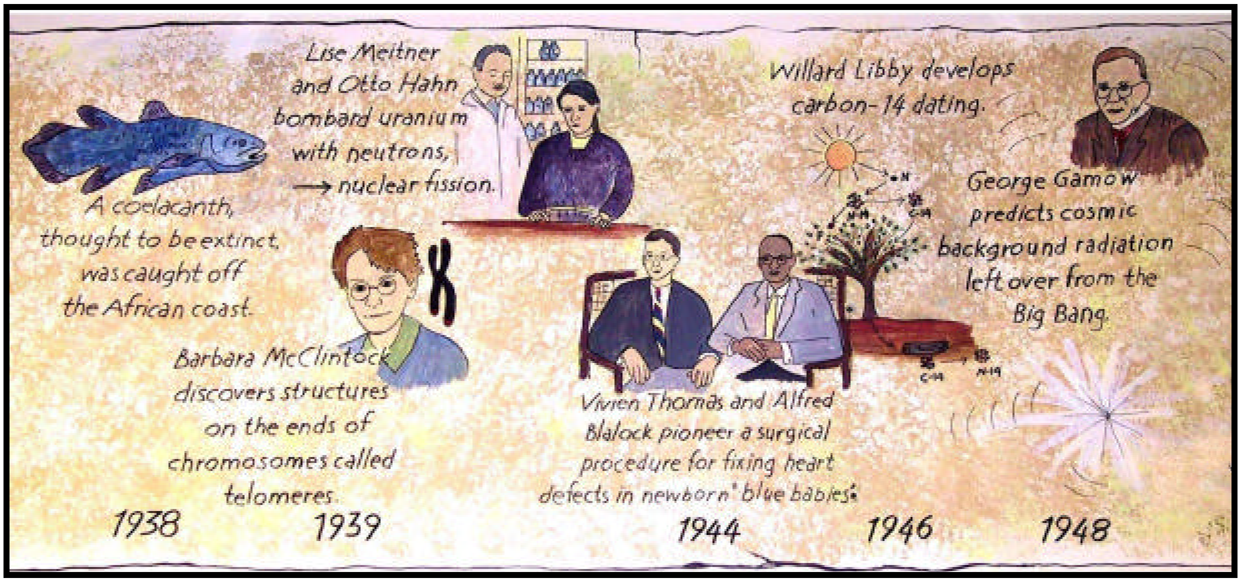

Christine G. Schnittka

Journal of Virginia Science Education
The peer-reviewed journal of the Virginia Association of Science Teachers
November 2006 Volume 1 Number 1

Theme: Standing on the Shoulders of Giants

"If I have seen further it is by standing on the shoulders of giants."
Isaac Newton, *Letter to Robert Hooke, February 5, 1675*

Research and Practice

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Research and Practice continued

52 **A Comparative Study of Chemistry Education in China and the United States**
Pinpin Peng and Juanita Jo Matkins

There are marked differences and similarities between the way chemistry is studied in China and the United States. Comparisons of education goals, curriculum and textbooks, chemistry teacher profiles, classroom teaching methods and learning approaches, and chemistry lab activities show the strengths and weaknesses of chemistry education in each country, as well as, exposing the possible challenges facing current inquiry-based reform efforts in both countries. The authors believe that through international mutual investigation, Chinese educators and American educators can learn from each other to accelerate the process of achieving their education goals.

65 **Why Is Teaching the Nature of Science So Important?**
Erin E. Peters

Explicit instruction about the nature of science can enrich science classes at all levels. Embedding such instruction in activities ranging from lab experiments to free-flowing class discussions can support student critical thinking skills as well as provide them with a framework for deeper understanding of the lesson at hand.

72 **Creating a Timeline of Science History in Your Classroom**
Christine G. Schnittka

The University of Virginia's science education lab hosts a colorful timeline mural of the history of science. Painted and designed by graduate student Christine Schnittka, this mural begins with the 1531 sighting of a comet and ends with its 2061 predicted return. The mural contains many familiar scenes with recurring themes, reflecting the changing face of science. Students at the University are learning a little more science history each time they come to class. Justification for and process of creating the mural, and a link to a website with images of the entire project are included.

Review

79 **Current publications affecting the teaching of science**

Science, Naturally!'s new book, *101 Things Everyone Should Know About Science*, offers a friendly question-and-answer format that will give non-scientists a way to familiarize themselves with some of the science basics and biggies.

Call for Submissions

"All children need and deserve a basic education in science, mathematics, and technology that prepares them to live interesting and productive lives," wrote Rutherford and Ahlgren in 1990.

This still highly relevant quotation from *Science for All Americans* serves as the reference point for the second issue of the *Journal of Virginia Science Education*. In this 'Science for All Virginians' issue, we invite papers that address the place of democracy, diversity and equity in science teaching and learning. Papers should examine the challenges educators face as they attempt to make science available and accessible to Virginia's increasingly diverse population, as well as practices they have developed to meet those challenges. In addition, manuscripts will be considered that deal with other current issues, classroom practices, or community projects addressing science education. For more information, visit vast.org
Deadline for submissions is February 2, 2007.

Journal of Virginia Science Education
The peer-reviewed journal of the Virginia Association of Science Teachers

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From the VAST Executive Director

As I sit down to write this piece for the first issue of the *Journal of Virginia Science Education*, I find myself teary eyed. Who would imagine that I would be involved in the evolution of so ambitious an idea from its conception to its birth? I can remember a small group of us putting this idea out to the full VAST Board. They had so many excellent questions: How would we achieve this goal, some asked? How would we make it different from the newsletter, others wondered? How could this support VAST's effort to improve the quality of science education throughout the state?

Months later, here we are, the *Journal* in hand. We were apparently able to answer all those questions to the satisfaction of enough Board members that the *Journal* has become a reality. Reflecting back, I feel it's necessary to give credit where credit is due: the entire Task Force dreamed and worked together to create this reality, but it was especially Juanita Jo Matkins who massaged and tweaked and nudged and cajoled, helping us decide the who's, what's, when's and where's that enabled all this to happen.

I encourage you all to find and thank these members and editors who made the dream come alive.

Susan Booth

From the VAST President

How appropriate it is that the theme of the Virginia Association of Science Teachers' first online journal is "Standing on the Shoulders of Giants." In our classrooms we encourage our students to practice the communication process we call the scientific method. The process can be brief, lasting only as long as a one-period inquiry investigation where students build their knowledge base by sharing the results of their work; or it can be more dramatic and sustaining, when students carry out their own research projects over the course of a year or two and then take the risk of reporting back to a public audience. In either case we allow them to stand on the shoulders of student scientists who came before them. The passing of knowledge becomes a lifetime pursuit when we all stand on the shoulders of those who came before us so we can create a future that will have room for strong and self-sustaining science education.

I would hope that you, the readers of this first issue of the *Journal of Virginia Science Education* will soon provide shoulders for others to stand on, as you submit reflections, research or revelations about the science you teach for forthcoming issues of the *Journal*. Let us know how you and your students continue to "Stand on the Shoulders of Giants." What better skills can we model and pass on to our students than to show them that taking risks in support of your beliefs advances the overall knowledge of the scientific community?

The ancient Sumerians' first writings were pictograms on clay tablets. In the Middle Ages scribes painstakingly created artistic text and images called Illuminations. In a communication quantum leap Gutenberg's printing press made documents available in unimagined numbers, eventually spreading worldwide, to the masses on every continent. What would all these precursors think of e-publishing and Flash animation that surrounds us today? We don't stand only on their shoulders, though: this peer-reviewed journal follows the lead of other scientific organizations, as we publish professional articles in keeping with the ground-rules and expectations they have established. In doing so, we stand on the shoulders of giants in the science education community.

I must extend my appreciation and thanks to the VAST Journal Task force led by Vice President Juanita Jo Matkins, and Susan Booth, VAST Executive Director. The two of them provided the leadership and vision needed to make this dream a reality. We must also thank the authors of the articles included in this first issue for being willing to go the peer review process, and the editors who finalized the format.

As president of VAST I have been committed to empowering the people who help run this organization. I have wanted them to risk seeing their own visions and dreams of where VAST needs to go as an organization come to fruition. Our newly redesigned web site is just one piece of evidence that this is taking place, and, of course, the debut of VAST's online peer-reviewed journal is another. It is your journal to read, to use in the classroom, to stimulate conversation...and for which to write. Enjoy!

Deborah Hamilton

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From the Editor

We were all set. The staff was hired. The call for papers was posted on the VAST website. VAST Board members emailed the call for submissions to colleagues. Then we waited, wondering.

Would anyone submit? And if they did, would the submissions be suitable? Would we find enough qualified peer reviewers, and would they get their suggestions back to us promptly? Would the authors be willing to take their peers' criticisms, and in some cases to undertake serious revisions?

Our worries, it turned out, were groundless. The papers arrived. The reviewers carefully but quickly analyzed them and made meaningful recommendations. The authors revised their work eagerly and efficiently.

And presto, we present to Virginia's community of science educators Volume I, Number I of the *Journal of Virginia Science Education*, replete with interesting, thought-provoking, well-written papers. These cover a wide range of topics that should be of interest to science educators of all ilks:

- several personal reflections: on how others helped them become science teachers, on the role of women in science, and on the many shoulders scientists themselves stand on;
- action research projects on student demonstrations, on student-developed graphics, and on the study of a millennia-old maybe-proto-battery, all geared to improving student performance;
- analyses of the role of critical thinking in science education, of the importance of teaching the nature of science, and of the similarities and differences between chemistry instruction in the US and China;
- insights into the impact an exotic field trip and a history of science mural can have on student understanding.

What a pleasant surprise to find Virginia's community of science educators—classroom teachers from a wide variety of fields and grade levels, graduate students, professors—willing to reflect carefully on their own experiences and to craft articles that other science educators—working in all fields on all levels—can profit from.

Our work, of course, has only begun. The Journal Task Force has decided on a theme for the second issue: Science for All Virginians, building on Rutherford and Ahlgren's premise that "There are no valid reasons – intellectual, social, or economic – why the United States cannot transform its schools to make scientific literacy possible for all students." In this issue, we invite papers that address the challenges posed by Virginia's increasingly diverse student populations and practices designed to meet those challenges. For the second issue, as for the first, papers on this theme, as well as on a wide range of topics and activities will be considered, including reflections on classroom methods and activities, on current issues in science education, on original research related to science education, among others. The deadline for submissions is February 2, 2007. There's more at www.vast.org.

We welcome you to Volume I, Number I, of what we hope is only the beginning of a long and fruitful online relationship among committed colleagues. We look forward to hearing from you—your letters to the editor, book reviews and articles—in the near future.

Nick Boke
Managing Editor

Broad Shoulders

Larry G. Aaron

Sir Isaac Newton's statement that he stood on the shoulders of giants in his scientific achievements seems almost flattery. He, after all, was probably the most brilliant scientist to stride across the planet. Yet, it was the work of others—from Euclid to Galileo and beyond—that opened the doors for his own seminal insights. Newton's laws of gravity and motion were built on the theoretical base of past discovery and succeeded in revolutionizing accepted thought about our universe.

I have read enough about Isaac Newton to know I'm no Newton. My successes have been nano size by comparison—a child here and there whose interest in some aspect of nature I have ignited. However, I can still say with Newton that I, too, have stood on others' shoulders, though my take on that may be different from his. It was, in fact, because of others that I became a science teacher in the first place.

Originally I wanted to be a scientist, so I majored in biology at college. After recognizing that making the big discovery that would put me on track for the Nobel was not in my future, I sought a different direction. At one point I even applied to be an astronaut. But neither I nor my application ever got off the ground. My epiphany occurred when I became a science teacher. I found it was my niche, and developed a passion for it. I guess I learned that where your feet hit the ground is likely where you're supposed to be.

What I have tried to do in more than 25 years of teaching science is to push students to go beyond where they are, to take them places in their minds they've never been, to unlock the secrets of their world and put them into another. I've tried to expose them to the world they see every day but hardly notice: a drop of pond water pregnant with myriad micro flora and fauna, the weather in a cloud, the story of a shapeless and uninviting rock from their backyard, or the secrets of outer space revealed in the glowing but silent beacons of the night sky.

I believe science starts with this curiosity about the world around us. A story about Sherlock Holmes and Watson has them lying down, looking upward during a camping trip. When Sherlock asked Watson what he saw, Watson replied, "I see stars." Then Watson asked Sherlock the same question. Sherlock turned to him and said, "What I see is that somebody stole the tent."

A lot of people stare into the sky, see "the stars are out," but never go beyond that—they're headed to a party or a meeting—with only a passing glance at those orbs of wonder that turn the heavens into a chandelier every night. Who stole the tent? Who stole the curiosity and the questions and the enthusiasm for what surrounds us? Einstein, who changed our views of the universe as radically as Newton, said, "Curiosity has its own reason for existing. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality." He also believed, "Imagination is more valuable than knowledge."

I have had shoulders to stand on that stimulated these things in me. Men and women who inspired me just by being around them and taking their pulse on what's out there.

I have realized that very little of my inspiration to pursue science and later teaching came from mundane homework assignments, or from the teachers who droned on and on—with much ado about nothing, lifeless in their enthusiasm, jaded by their journey through teaching. Einstein, three-quarters of a century ago, expressed sympathy with the plight of many of today's students: "It is, in fact, nothing short of a miracle that the modern methods of instruction have not entirely strangled the holy curiosity of inquiry."

Some of the shoulders I stood on that excited that holy curiosity were scientists or teachers, but not all.

When I was 4 or 5 years old I remember very vividly a moment that changed the way I looked at nature. Both my parents worked second and third shifts in a textile mill, so my sisters and I had a nanny of sorts. I can still see her—an older black woman, wrinkled of skin, with a flair for kindness. She made sure my sisters and I were fed, got our baths, and went to sleep on time. We learned to depend on her and felt comforted by her care.

One evening she took me to the living room window. My chin barely came to the bottom of the window frame, but I could easily look up and see out the glass pane. There in front of me was the bright full circle of the moon. I had noticed it before of course, but she said to me, "Can you see the man in the moon?" I could not, so she started pointing out the nose, eyes, mouth—and finally, like a light bulb coming on—I saw it. The moon came to life that evening and it has never been the same for me. I realized that what you see is not all that's there.

Still today, when I see the full moon, I look for the face that seems to be smiling back at me, and I remember that other face that pointed me to the sky. I am sure she never knew the impact she had on me in that brief time. But she ignited my curiosity and fired my imagination.

When I was in junior high school, I met another giant—a local naturalist name Johnny Westbrook. He knew everything about nature, I thought. At least I was sure he knew more than my science teacher. He collected specimens of everything, sometimes trading with people around the world. He used to pile us kids in his old station wagon on Saturdays and take us here and there, showing us the great outdoors, while we roamed the countryside collecting this and that.

But he also got some of my pals and me in trouble—big-time trouble over an insect collection our science teacher had assigned each us to collect. That's because we were supposed to do our own collection—which we attempted—though we were all dissatisfied with getting only nondescript varieties of ants, wasps, and grasshoppers. Perhaps we would find a praying mantis if we were lucky. At last some of my classmates and I came upon a great idea—go to Johnny and see if he could help us. We knew he had lots of exotic, neat-looking critters. Sure enough—I ended up with a brilliant blue butterfly from South America as a centerpiece for my collection.

When the other boys and I got our collections back, we all got C's instead of A's. The teacher was upset with us and said she knew that the collections weren't all our work. She scolded, "I know some of you went down to Johnny's." So we were all punished with a lower grade. I know she was right—we should have gotten our own bugs. But for the life of me I can't remember her name, or any particular thing that she taught me. But I do remember Johnny. Today in our community, we who knew him are referred to affectionately as *Johnny's Kids*, and numbers of us have gone into some avenue of science.

There are other shoulders I stand on. There are my parents, who always made sure we had *National Geographic* Magazine. Each issue was filled with the science of far away places—such wonders that made me dream of all that was out there.

There was a physics teacher in high school who tossed the textbook and gave us opportunity to investigate in one experiment after another. His approach actually boosted our inductive reasoning ability, and we had fun at the same time. A lot of fun as I remember. We spent more time doing than listening—but always learning. And today I still love Physics.

And then there was Dr. Wayland, the head chemist at Dan River Mills' well-known textile laboratory in my hometown. When I called one day during my high school years to ask if I could visit the lab, he graciously invited me and showed me around, seemingly unhurried even though I was by myself and he no doubt was busy. I don't remember what he pointed out to me or what activities were going on. I just remember that he took the time to encourage a kid about the wonders of chemistry.

So, the shoulders I stand on are not those who merely instilled rote knowledge in me (although such knowledge is important), but those who set me ablaze with the desire to learn on my own. In one way or another they were all teachers, whether they realized it or not, and they taught me more than science. They taught me how to teach.

Today, I try to follow their example and expose kids to nature any way I can. I want them to meet people doing science. I want them to discover and explore. And just like the poet T.S. Eliot said in *The Four Quartets:*

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

The way we learn about life best is by exploring—that child of curiosity and imagination.

Science teaching is not about showing off our brilliance or how tough our tests are; it's all about being a chef, and feeding the hunger for discovery and exploration that is a natural part of the human psyche.

George Mallory, the legendary mountain climber who died on Mt. Everest, said "A great mountain is always greater than we know; it has mysteries, surprises, hidden purposes; it holds always something in store for us." Science is like that too. The best part of being a teacher is helping others climb that mountain. To do that they need pairs of shoulders to stand on to reach a little higher. My goal as a science teacher is to be someone who offers those shoulders. After all, other someones did it for me.

Larry Aaron is Chairman of the Science Department and teaches Earth Science, Astronomy, and Human Anatomy and Physiology at Chatham High School in Chatham, Virginia.

Development of Atomic Theory

By Robin Curtis

To help my students learn the parts of the atom, I often asked them to create a time line showing the development of atomic theory. The strategy helped students not only to learn the different parts of the atom, but also to understand that philosophers and scientists did not arrive at the atomic theory single handedly. The students saw that each succeeding person would build the concept from a previous idea. Atomic theory provides a good example of this phenomenon: from the earliest known theories to our contemporary understanding of atomic theory, philosophers and scientists have “stood on the shoulders of giants.”

The first atomic theories we know anything about were philosophical rather than based on scientific experimentation, and arose in two different regions. In the 6th century BCE, Indian philosophers propounded ideas about the atomic constitution of the material world. These earliest atomists believed that an atom could be one of up to six elements, with each element having up to 24 properties. Pakudha Katyayana also developed detailed theories as to how atoms could combine, react, move, vibrate and combine, believing that atoms would combine in pairs and then into trios of pairs, which would be the smallest visible units of matter.

Not long afterward, far to the West, the Greek natural philosopher Democritus stood on the shoulders of his teacher Leucippus, who had suggested that the universe was made up of empty space and atoms in the 5th century BCE—we have no evidence of communication between Greece and the Indian Subcontinent about these matters, though it may, of course, have existed. Democritus, who was the first to call an atom “atomos,” held that an atom was indivisible, indestructible, and unchangeable. These Greeks believed that atoms had different sizes and shapes, and the size and shape determined the physical properties of the material. For example, the atoms of a liquid were thought to be smooth, which would allow the atoms to slide over each other.

The giant of Greek scientific and philosophical thought, Aristotle, fiercely argued against atomism. His arguments held sway for around 1,500 years, as he influenced the Roman Catholic theologians who dominated Medieval scientific thinking, so atomic philosophy fell by the wayside. The seeds of atomism remained, however, contained in the Roman Lucretius’ *De Rerum Natura* (*On the Nature of Things*), which was written in the first century, CE. Lucretius was among those who caught scholars’attention after the 15th century CE as Renaissance humanists began to unearth, translate and discuss Greek and Roman texts.

True scientific experimentation began in earnest with Sir Isaac Newton in the late 17th and early 18th century and as other scientists began to discover and organize elements. This laid the groundwork for the further development of the modern atomic theory. In 1803 Joseph Louis Proust, a French chemist, provided experimental proof of his law of definite proportions, which says that a molecule will always contain the same number of its components, no matter how it is prepared.

John Dalton stood upon Proust’s shoulders to develop the law of multiple proportions. Dalton’s efforts to explain the formation of nitrogen dioxide instead of dinitrogen trioxide when he doubled the amount of oxygen used in the combination, led to the development of his theory of atoms. Dalton proposed that an element is composed of atoms of a single, unique type, and that although their shape and structure is immutable, atoms of different elements could combine only in small whole-number ratios to form more complex structures, and atoms of different elements had different weights. Dalton's method for actually determining atomic weight was the distinguishing feature of his work. He was also the first to propose standard symbols for the elements.

The idea that an atom is in continual motion came from biologist Robert Brown. In 1827 Brown observed that pollen grains floating in water were constantly jiggling about for no apparent reason, the so-called "Brownian Movement." In 1905, Albert Einstein stood on Brown's shoulders and theorized that this jiggling movement was caused by the continual motion of the water molecules. Einstein, whose main interest was energy, was able to use Brown's observation to support the kinetic molecular theory "that atoms and molecules are always in motion." The theory was then mathematically demonstrated by French physicist Jean Perrin in 1911, who by validating the kinetic molecular theory, further validated atomic theory as well.

The next part of the story deals with how the theories of the physical structure of atoms were developed. The first idea of the existence of subatomic particles began in 1897 with J.J. Thomson's discovery that cathode rays were streams of negatively charged particles. Thomson was the first to suggest that the so-called electrons were a part of the atom. He used the word "electron," suggested by G.J. Stoney, an Irish physicist (although many of our text books give this honor to Benjamin Franklin). Thomson, a physicist at Cambridge University, also tried to show how the electrons were situated in the atom. In 1904, Thomson proposed that the atom was a positively charged sphere randomly studded with negatively charged electrons, which made the atom neutral. Thomson's model was called the "plum pudding" model because he thought the atoms were randomly distributed like raisins ("plums") in a plum pudding.

For the discovery of the nucleus of the atom in 1911, Ernest Rutherford, a student of J.J. Thomson, performed scientific experiments that involved shooting alpha rays through a thin gold sheet and onto a screen. The data collected from the experiments led him to describe the atom as a small, very dense nucleus with electrons in orbit around it and a lot of space. He came to this conclusion because not all the alpha particles went straight through the gold foil to the screen; some were deflected and a very few were surprisingly reflected. The alpha particle (we now believe to be composed of two neutrons and two protons) could only be deflected or reflected by an object that was denser than an alpha particle. Rutherford stood on Thomson's shoulders and disproved the "plum pudding" model.

In 1913, Danish physicist Niels Bohr who was a student of both Thomson and Rutherford, stood on the shoulders of Thomson, Rutherford, Planck and Einstein by incorporating the idea of Max Planck and Albert Einstein that light energy is emitted or absorbed in fixed amounts known as quanta. Bohr proposed that electrons would orbit the nucleus of the atom in a particular circular orbit with fixed angular momentum and energy. The electrons would not spiral into the nucleus because they could not lose energy in a continuous manner, but they could make quantum leaps between fixed energy levels.

Further experimentation with splitting atomic nuclei in 1919 led Rutherford to the discovery of the proton. A proton carries a positive charge and every atomic nucleus contains one or more protons. In 1920, Rutherford proposed the existence of a neutral subatomic particle but this discovery was actually made by someone standing on Rutherford's shoulders in 1932, one of his former students, English physicist James Chadwick.

With this conclusion, the general picture was complete—the neutral atom has a nucleus that contains protons and neutrons with electrons in various orbits outside the nucleus. This particular chapter of the story of scientists standing on the shoulders of those who came before them in their search for a basic understanding of the atom ends here.

The story has, of course, continued on in the same way as scientists have discovered more and more about the atom, including worlds of subatomic particles absolutely undreamed of by Leucippus and Katyayana more than two millennia ago. One scientist learns and builds ideas. The next takes those ideas just a little farther. Knowledge moves from teacher to student, and then the student becomes another's teacher. In the end each of these giants has contributed to the big picture of the modern atomic theory by standing on the shoulders of the preceding giant.

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Robin Curtis is the NSTA District VIII Director. She has won numerous awards for her teaching and has served as President of VAST.

Standing on the Shoulders of Giants
(*and how to join them*)

Bonnie J Keller

Teaching today is not what it was twenty or thirty years ago, when “networking” with other teachers meant chatting in the teacher’s lounge. The modern era of computers has opened new possibilities for interactions with colleagues. Moreover, the colleagues can be from anywhere in the world. What follows is my parable of how I survived my years as a new teacher and went on to become someone on whom others now depend.

When I began my college education, I took many courses on education theory, educational methods, as well participating in several pratica. These courses were intended to introduce me to the wisdom of ages of educators and researchers so that I might enter the classroom with at least a few good teaching tools to use in my teaching career. However, what these courses did not provide, for the most part, was an opportunity for me to talk with experienced teachers. Missing, for the most part, was any opportunity to talk to other teachers who had walked in my novice shoes, and could give me the real “dirt” on what had worked for them (or hadn’t). I found these courses to be mostly a waste of my time, as I craved real-world info, not theories of how teaching and learning should happen.

In fact, from all the courses I took on education, I can remember only one day of one of them, and that was a day when we had a guest speaker who had been a teacher for many years. But her advice wasn’t about teaching—it was about how to save money and prevent burnout by avoiding working late at home. These are important lessons, of course, but not lessons that helped me much with my day-to-day teaching.

My first year of teaching earth science in 1993 was in an urban setting, complete with crumbling building, sky-high absenteeism, and five different classrooms to teach in (two of which weren’t even science rooms!). That was a trial by fire, in the best sense of that phrase. How did I survive? By making connections with other teachers who already had years of experience. You see, I had learned about Bulletin Board Systems, or BBS’s as they were called. This was in the early days before the widespread use of the Internet as we know it, and we used a 2400 baud modem to dial into various computers that had been networked to other computers via phone lines or satellite dishes. I found a community of teachers on one network, and “met” them online throughout the year to exchange information. For me, it was mostly a chance to soak up ideas and lesson plans and anything else that these seasoned classroom warriors would provide me. One in particular, Keith McKain, regularly mailed me packages that contained copies of worksheets, handouts, and other information. He was from Delaware, and I probably could not have completed that first year without his generosity.

After that high-intensity first year, I left that school for a smaller setting, and lost touch with my friend Keith. I never forgot him, though, and continued to look for communities of teachers from whom I could glean knowledge, as well as wisdom. My life took me to another state, a short-term change of careers, a brief stint at a wonderful example of what juvenile detention education can and should be, and then returned me to Virginia and to public schools. All the while, the Internet was growing, and the network of Bulletin Board Systems had been replaced with networks such as AOL and

Compuserve. While the larger networks lacked the quaintness of the original forums, they certainly made up for it by offering a much broader choice of communities, and I found myself being the one that other new teachers were asking questions of. I joined AOL's Homework Help area, and become the earth science board leader and chat room host.

Eventually this led me to another community on AOL that was about pets, rather than classroom related, but one of my fellow hosts there was also an earth science teacher. We stayed together as this particular forum left AOL and moved from website to website. During those five years of expansion and movement, Cheryl and I exchanged a few pleasantries, but since we'd met through a shared hobby, we did not talk a lot about education until sometime in the fall of 2002. One evening she offered to send me some of the lessons that she'd been using. She also sent me an e-mail that had originated from a group in New York calling themselves ESPRIT: The Earth Science Program/Resource Innovation Team. I was intrigued, and looked at the website. The listserv clearly stated that it was for earth science teachers from New York, but I e-mailed the moderator, Dr. James Ebert of SUNY-Oneonta. I requested his permission to join, despite my being "geographically challenged" in their eyes. He responded immediately, and welcomed me with open arms.

It has now been three and a half years since I joined the ESPRIT listserv. During that time I have been exposed to several hundred other earth science teachers, mostly in New York state. There are others, however, from all over the USA, and some from other countries. Some are K-12 teachers, others work at the college level, and still others are in informal education settings. And, of course, there are others who formerly belonged to one or more of those groups, but have since retired. I have met Thom McGuire, author of an outstanding earth science review text. I have made contacts with numerous other outstanding educators, including past and present officers of the Geologic Society of America, National Association of Geoscience Educators, National Science Teachers Association, and various state organizations. All of this excellence has been focused into this one spot in cyberspace, and I lucked out in finding it, tapping in, and absorbing as much as I possibly can.

In these last few years, I have enjoyed witnessing other new teachers grow from their first timid posts to becoming those who answer questions asked by even newer teachers. I have experienced the swell of confidence as I have learned details of science that I never covered in my undergraduate education, which would have cost me many thousands of dollars to have gleaned from those same people in courses and workshops. I have watched my own students benefit from the tips on classroom management, lesson plans and activities shared by other list members. I have collaborated with the group in constructing new activities that were in response to current events in earth science. It is not unusual for my mailbox to receive 100 messages per day, most of which I devour hungrily, even when the subject doesn't seem to pertain directly to me or to my work.

I have also found myself being one of the "regulars" who posts and responds to new members, assures them that they are on the right track, and coaxes them to share their own experiences. I am in awe, knowing that I was in their shoes but a moment ago – or so it seems.

So there you have it: in the last 13 years, I have grown from being a scared new teacher who stood on the shoulders of giants to becoming one of them. I just try to be one of the friendly giants, rather than one of the unpleasant ones the Grimm brothers might have conceived. I encourage new teachers and veteran teachers alike to find a community online of others who share your struggle. Learn from them, grow with them, and become one of them. You will find, as I did, that joining such a community will be more valuable than any course you ever take, any workshop you ever attend, or any other professional development you ever encounter. Consider it an ongoing exchange with giants.

Oh, and guess who joined the ESPRIT listserv last year? Keith McKain, my long lost “giant.” And yes, he’s still teaching. I hope to someday meet him in person - giant to giant.

Online resources for teachers

1. http://external.oneonta.edu/mentor/listserv.html
The OMNI listserv subscription page serves the following forums:

Esprit	This listserv provides a forum for discussion and professional support of science teachers engaged in teaching New York's Commencement Level Physical Setting: Earth Science Core Curriculum.
BioForum	This listserv provides a forum for discussion and professional support of science teachers engaged in teaching New York's Commencement Level Living Environment Core Curriculum.
5-8Science	This listserv provides a forum for discussion and professional support of middle level science teachers engaged in teaching New York's Intermediate (5-8) Science Core Curriculum.
Ophun-L	This listserv provides a forum for discussion and professional support of science teachers engaged in teaching New York's Commencement Level Physical Setting: Physics Core Curriculum.
Nestling	This listserv provides professional support for teachers of K-4 science. NESTLING stands for Nurturing Elementary Science Teaching. Mentoring is available from veteran science teachers.
ChemBond	This listserv provides a forum for discussion and professional support for science teachers engaged in teaching in New York's Commencement Level Physical Setting: Chemistry Core Curriculum.

2. http://www.discoveryeducatornetwork.com
The Discovery Educator Network is a global community of educators who are excited by the power of digital media and want to collaborate and share resources with other teachers. The Discovery Educator Network web site is a place for educators to share ideas, information, and activities. There are a variety of tools available and varying levels of access.

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Femineus Physicus: Women Scientists, The *Other* Giants

Rhonda White

Strategies to close the gap between boys and girls in science will ensure the continuation of a female contribution to science.

Introduction

We stand on the shoulders of giants. As we look into our future, it is important occasionally to look down to see upon whose shoulders we stand and upon whose past accomplishments we build. Many would no doubt be able to name numerous ground-breakers in science. One may immediately think of Mendel's genetics or Franklin's electricity, Einstein's relativity or Faraday's electromagnets. Of course, these great figures and their counterparts deserve proper homage and respect. But let us also consider others who are constantly overlooked. Unfortunately, one gender is often disregarded or underrepresented when scientists, inventors and innovative thinkers are credited for their work. This is a test: How many women of science can you name?

At the beginning of each school year, I hand my fifth-grade students a blank sheet of drawing paper featuring a computer-generated frame. I ask them to draw a scene of a scientist at work. For the first few minutes most of them stare at me as they attempt to figure out what I really want them to do. After I repeat my directions I add, "What do you think a scientist at work looks like?" Finally, the students begin to draw. Over the past eight years amidst the usual sketching, coloring, small conversation and general hum of an elementary classroom, I have found a common thread: in scene after scene, people of all races are represented wearing more white lab coats than I care to count, doing an endless number of activities. As I display the collection for the entire class to admire, I pose the question, "Can we make any generalizations from what we observe in these pictures?" The students might argue that certain activities do or do not denote "science," or that the scientists do not have to don a white lab coat, glasses and sport a fluff of white hair. Eventually, someone in the class has an epiphany: "Hey, there are more men in the pictures than women!" One year, that was followed by a female student complaining, "And there are more of us (girls) than boys in here right now! What gives?"

What an excellent question! Where are the women in science? Are we providing enough incentives for our female students to want to participate in professions related to scientific discovery? Are we as science educators encouraging their interest by offering them role models to emulate? Where is the homage and respect that is due to these unsung but noteworthy giants of science? Why in this otherwise progressive world aren't there more female scientists? Women have been innovative scientists for as long as men; however, one would not always realize this when the faces on science timelines rarely include females. Or, as my students have shown me year after year, even many eleven-year-olds are aware of and hold strong gender stereotypes.

Current Trends

Critics may question: Hasn't the gap closed? In the late 1990's Congress requested a report about the issue; enter the *Trends in Educational Equity of Girls and Women* report. One finding from this report states that the achievement gap in science has decreased; however, it also says that girls are less confident in science than boys (Bae, 2000). This is important because this finding supports many of the gender achievement problems in education and the workforce.

Another study finds that by age 17 the science gender gap has widened and is undeniable (Manning, 1998). Moreover, in college more males are choosing science majors, especially on the graduate level. This trend is known as the "leaky pipeline" (Lebarkin, 2003).

Suggested Experiences

What can be done on the foundation levels of education (elementary and secondary) to eliminate the achievement gap? I try to dispel whatever misconceptions my students have at our yearly commencement. I have employed the following strategies with all of my fifth-grade students regardless of gender, ability level or other factors. These efforts let us marvel at the work of female scientists in context to our units of study.

Find a supporting organization

Cooperating Hampton Roads Organizations for Minorities in Engineering (CHROME) is a non-profit K-12 outreach program whose primary goal is to identify, nurture, and assist qualified minority and female students to succeed in engineering, science, mathematics, and related technical fields. The organization is based at Old Dominion University.

As a CHROME sponsor, I assist my students in realistic and relevant scientific projects, mathematics constructions, career development planning and critical thinking related to their world. I accompany them on field trips such as local hardware stores in search of building projects. The female members were eager to participate, even on the weekend. The girls became involved in a "science club," not a common membership for the gender. Finding a supporting organization helped me to develop activities and locate resources.

Other organizations have been established with similar educational equity goals. The Graduate Women in Science Organization was established in 1921 (www.gwis.org). Its purpose is to foster women who want to achieve science degrees. Similarly, the Association for Women in Science is a noteworthy organization established in 1974 (**www.awis.org**). It can be used as a source for grants. Educators and students may join these organizations to have access to resources and educational opportunities.

Use the Internet

Technology plays a key role in finding information about notable female scientists. There are sites on the Internet that highlight women of the past and present in order to inspire women in the future. One such site that I have found helpful is called "Women in Science" (**http://www.womeninscience.org/**) It is truly unique in that it has a mentor section that offers brief biographies of female scientists of the present and their contact information. This is a great tool for a student to use when completing a science project. The students get firsthand information from someone who works in the field. This type of input is inspirational and motivational to a budding scientist of any gender. Students enjoy this site and often visit it "just for fun."

Mentoring programs have been established at other websites such as the *Women of NASA* (**http://quest.arc.nasa.gov/women/intro.html**) sponsored by NASA. This site also has a discussion section called NASA Quest Chats which entertains topics as the gender achievement issue in science.

Another highly navigable, informative and versatile site is titled "4000 Years of Women in Science" (http://www.astr.ua.edu/4000WS/4000WS.html**)**. The site contains many biographies of women in disciplines ranging form astronomy to zoology. Scientists can be searched alphabetically or by field of study. In addition, students can search by time or period. For example, they can search for scientists solely from the Middle Ages. My students especially liked photographs of scientists as they could connect an image with an accomplishment.

Use Graphic Organizers

Venn Diagrams can be powerful tools to show similarities and differences. As a part of developing literacy, try creating Venn Diagrams with scientists that students are required to learn about according to curriculum standards. Do this with a lesser-known female figure. When studying space exploration, students can complete a Venn on Dr. Mae Jemison and Neil Armstrong (4.7 of the Virginia Standards of Learning for grade four). Although this goes beyond what is required according to the Standards of Learning, I believe the Standards should be springboards to greatness not a ceiling for activities.

As an elementary school teacher, I love for my room to show what I am teaching. Students can "read the walls" and reflect at any moment about what they see surrounding them. A project which I often assign is the creation of visual aids such as timelines. I have my learners create a science history timeline, encouraging them to add women of special interest in science. These products can be computer generated using a spreadsheet in Microsoft or a graphic organizer program such as Inspiration. Also, this is a great cumulative activity on the Who's Who of science for a specific grade's curriculum.

Using drawing software, students can generate graphic organizers outlining current women of science as heard through interviews on an online radio website, *TECH Club* (**http://womeninscience.org/tech.htm).** It is part of research being done by students at the Academy of Holy Names in Albany New York. They introduce present day females whom use science and technology in their work. Students can also use this as a model to create their own interviews and reports with local female scientists.

Celebrate Women

March is Women's History month. Teachers often review and discuss the contributions of a select group of women, usually those with whom we are already familiar such as Marie Curie or Madame C. J. Walker. Why not extend this knowledge? If you are truly interested in Women's History, especially in science, immerse your students in this rich history.

To begin a unit, assign a brief biographical sketch of a woman who has contributed to the unit of study. For example, Jeanne Villepeux-Power is researched when beginning oceanography (Women in Science, 2006). Of course, this could be a language arts activity, including men as well. Collaborative groups are assigned to upcoming units and present their research to engage their peers.

Another way to celebrate is by awarding classroom "Nobel Prizes" for science research and projects. A springboard for this celebration can be a search of the Women Laureates of the Nobel Prize in Science. Of course students will come across familiar names such as the physicist Marie Curie, but they will also encounter more recent winners such as the biologist Linda Buck.

Conclusions

We stand on the shoulders of the giants of science. But who do we see when we look to our right or to our left? Adhering to the mandates of No Child Left Behind legislation, we must attempt to reach all of our children as we elevate them above and beyond any boundaries, real or imagined. What better way to accomplish this for girls than to familiarize them with other females who have excelled in all aspects of science?

All students should become equally aware of the accomplishments of scientists of both genders and all races and nationalities. After all, the contributions and pitfalls of science such as nuclear power belong to us all. The gender gap in science is not as large as it has been (Milbourne, 2006). If we do not pay close attention to our instructional techniques and make conscious decisions to promote equity, however, we could revert to previously existing inequities.

In my classroom, I avoid this by searching for strategies that ensure gender equality in my instruction. I closely monitor the content of my lessons to make sure all groups are equally represented. More than anything I try to make lessons meaningful to all learners. In this way I help students want to learn more about unsung scientists. This has helped my female students to achieve, while maintaining the involvement of my male students. This past year in one of my science classes, the gender achievement gap was only 5%. Although this is an improvement from historical averages, I will not be satisfied until there is no gender gap in science at all.

Students should be challenged to celebrate the success of each scientist. We can teach our children that their gender should never limit their achievements. Their futures should limited only by their imaginations; they can achieve greatness in science and in life.

We stand on the shoulders of the giants of science. We use their research and findings to propel our own investigations and inquiries. Let us remember that those heralded as giants are not just men, but also women. I look forward to the day when my students draw as many women as men when completing my yearly intro activity. As Margaret Fuller once said, "If you have knowledge, let others light their candles in it." I hope that students are able to use the knowledge of all giants of science, regardless of gender, to enlighten the future of the world.

Resources

4000 Years of Women in Science. http://www.astr.ua.edu/4000WS/4000WS.html**.** A student and teacher resource from the University of Pennsylvania Museum, Philadelphia.

CHROME (Cooperating Hampton Roads Organization for Minorities in Engineering) Contact person: Theodosa Wyatt, **Twyatt@odu.edu** or call (757) 683-6035.

Virginia Department of Education Enhanced Scope and Sequence for Science - Grade 4, http://www.pen.k12.va.us/VDOE/EnhancedSandS/science.shtml**.**

Women in Science. http://library.thinkquest.org/20117/**.** A student and teacher friendly resource developed for ThinkQuest by N. Hassold, K. Thomas and A. Frerichs.

Wikipedia.com search key words: women in science: 20th century, female Nobel prize laureates in science fields.

WAMC Northeast Public Radio: **http://www.womeninscience.org/**

Women of NASA website: **http://quest.arc.nasa.gov/women/intro.html**

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The Elementary Science Classroom is the Place for Teaching Thinking

Patricia E. Buoncristiani
A. Martin Buoncristiani

A comparison of the Virginia Standards of Learning documents across the third and fifth grade curriculum reveals a significant focus on higher-order cognitive skills in elementary science classrooms. Science teachers need to be aware of this and address the teaching of skillful thinking so that it can be transferred to other disciplines and serve as a foundation for later learning. Researchers review recent research on brain function and discuss how this research can help the teaching of cognitive and metacognitive skills.

Introduction

Mathematician György Polya opens his book on problem solving, *How to Solve It* (Polya, 1945), with the admonition:

> "One of the most important tasks of the teacher is to help his [or her] students. This task is not quite easy; it demands time, practice, devotion and sound principles."

Polya, an excellent teacher himself, clearly recognized that teachers must possess, in addition to mastery of their subject, an awareness of their students' needs and the means to satisfy those needs. In short, "how you teach" is as important as "what you teach."

In this paper we will discuss the Virginia Standards of Learning and associated documents that serve as the source of curricular content for Virginia's teachers. This is the "what you teach." We will also discuss recent research on the brain and how it functions, emphasizing ways this recent research can promote student learning. This is the "how you teach."

The importance of excellence in science teaching is clear. Science has played a central role in the development of human culture and, through education in the sciences, it plays a vital part in the propagation of that culture. The United States is facing a changing world with globalization and evolving telecommunications technology providing more and more competition for our industry (Friedman, 2005). To maintain our position among nations we must continue to be the technological innovators we were in the last century. To do this we must have a steady supply of talented young people interested in science and engineering.

In our review of the Virginia Standards of Learning documents we have uncovered another reason to stress excellence in science teaching. As we hope to illustrate in a sequel article, an examination of the standards for English, Mathematics, Science and History/Social Studies shows that each of these disciplines sets the acquisition of higher-order cognitive skills as an objective. However, examining the tasks suggested by the standards documents to achieve these objectives we find it is the tasks in science that involve the preponderance of complex thinking (see appendix for details). Students learn many of their thinking skills in science. Science teachers need to be aware of the responsibility that accompanies this fact so that they can address the teaching of skillful thinking in a manner that allows these skills to be transported to other disciplines. The teaching of skillful thinking in the early elementary years provides an essential foundation for successful learning in later years.

Research on How People Learn

Recent research from widely divergent fields has led to a new view of the brain and how it functions. This has implications for how we can help our students learn. Research comes from three main areas:

> 1) The 1990's – the Decade of the Brain – generated more understanding about how the human brain operates than was acquired in the entire previous history of neuroscience. We are now close to being able to answer the fundamental question of how the mind emerges from the brain; that is, to determine the biological basis of the conscious mind. This approach to learning from the biosciences is from the "top down" (Damasio, 2001).
>
> 2) Cognitive and developmental psychologists have approached learning from the "bottom up." An understanding has emerged that learning requires an individual's introspection into how he or she learns – a metacognition. This process is complex because the mind is observable only to its owner. As teachers leading students in the development of their own minds we need to be aware of relevant pedagogical developments and we need to make our students aware of them (Bransford, 2000).
>
> 3) A body of "discipline-based educational research" is emerging in several fields (Hestenes, 1985). This is the study of learning in a discipline carried out by members of that discipline. From this research have come teaching and learning techniques adapted to that specific discipline (Crouch, 2001).

We first review the three pedagogical findings appearing in the National Academy of Science report "How People Learn" (Bransford, 2000). These provide a basis for the 'sound principles' Polya mentions in the quotation opening this paper.

Finding 1

Students come to the classroom with preconceptions about how the world works.

If their initial understanding is not engaged they may fail to grasp the new concepts and information that are taught, or they may learn them for the purpose of a test but revert to their preconceptions outside the classroom.

Student preconceptions result from their initial effort to figure out how the world works. These preconceptions (sometimes misconceptions) can be deep seated and difficult to change and often they seem able to "explain" the world at least partially.

Consequently, they may interfere with learning (Smith, 1993). If they are not addressed by the teacher and the student, essential learning may be thwarted.

A concept closely related to preconception is a student's prior knowledge. Marzano recognizes this in his elaboration of the strategy of "Cues, Questions & Advance Organizers" (Marzano, 2001), writing:

> "Educational researchers have shown that the activation of prior knowledge is critical to learning of all types. Indeed, our background knowledge can even influence what we perceive."

Finding 2

To develop competence in an area of inquiry, students must:
(a) have a deep foundation of factual knowledge,
(b) understand facts and ideas in a context of a conceptual framework, and
(c) organize knowledge in ways that facilitate retrieval and application.

Experts acquire new information and organize it differently from novices. Experts may transfer (teach) information but not their organization of that information. The organization must take place in the student's own mind and that means that students should think about how they learn and how they organize information they are presented. The process of "study" is largely about organizing information so that it can be accessed and used efficiently.

Finding 3

A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

By "metacognition" we mean more than just "thinking about thinking." As the word is used by cognitive scientists and educators, metacognition refers to the conscious application of an individual's thinking to their own thought processes with the specific intention of understanding, monitoring, evaluating and regulating those processes. Young children, even preschoolers, have demonstrated the ability to perform simple metacognitive tasks (Flavel, 1970, Butterfield, 1987). Furthermore, as they grow, children's knowledge base increases and so does their ability to monitor that knowledge (Schneider, 1985). There is growing evidence that young children can learn metacognition and that this ability facilitates subsequent learning (Bransford, 2000).

It is important to remember that the ability to think skillfully and to reflect on our thinking is not an innate human characteristic. These skills need to be explicitly taught to students. Research has shown that around 30% of the adult population does not engage in metacognition (Chiabetta, 1976, Whimby, 1980).

Effective learning will only take place when all three of these principles are an integral part of the curriculum. Teaching the 'stuff of science' may contribute to the development of a significant knowledge base, but without a conceptual framework to support it, it remains inert knowledge and students are unable to transfer what they have learned into novel or unfamiliar contexts. The ability to make these transfers is at the heart of innovation. David Perkins stated these ideas concisely (Perkins, 1992): "Learning is a consequence of thinking."

Examination of Virginia's Learning Standards

Many elementary teachers are required to teach across all four tested academic areas. In schools where there is a level of departmentalization teachers may teach grouped subjects – for example social studies and science, or science and mathematics. It would be an unusual circumstance for a generalist teacher in the elementary school never to be required to teach science.

Educators have long pointed to the importance of recognizing students' individual learning differences and needs. An effective teacher observes the students and adapts teaching techniques to cater to these differences. Good teachers also need to be aware of the discipline-based pedagogical research and the differences imposed by the forms of assessment that students are mandated to complete. The strategies utilized by competent teachers of science in Virginia will differ in many respects from the strategies required for teaching reading or history if the mandates of the Virginia Standards of Learning and the associated assessments are to be met.

It is worth comparing the requirements of science teaching in Virginia with the requirements for another fundamental curriculum area – history. By comparing both the curriculum content and the assessment requirements of these two disciplines it becomes clear that the science curriculum as it stands now is a fertile field for the development of skilled, flexible, innovative thinkers and requires teaching strategies that incorporate the development of flexible, adaptive thinking.

The Language of Instruction and Assessment in Virginia Studies

There are some fundamental differences in the language used in the grade 5 science and Virginia Studies curriculum frameworks. The introduction to the Virginia Studies Curriculum Framework lists the skills students should develop. Among others it specifies in VS 1 that students should be able to *"interpret," "evaluate," "analyze," "draw conclusions and generalize."* These skills are cited in the *"Essential Skills"* column of the document alongside each of the standards (VASoL History4). But an examination of the *"Essential Knowledge, Questions and Understandings"* in VS 2, for example, shows little or no opportunity for students to actually exercise these cited higher-order skills since they revolve, almost entirely, around locating and identifying geographical features. Using Bloom's taxonomy of cognitive tasks to analyze these criteria the focus is clearly at the "knowledge" level although there is an attempt to make it appear as if these are higher order "analysis" tasks.

In the Enhanced Scope and Sequence content for VS 2, the word "*know*" is used 14 times, "*locate*" three times, "*identify*" six times, "*recognize*" once, and "*describe*" is used twice (VASoL, Virginia Studies).

The summary of VS standards 2, 3, 4 and 5 shows a similar bias towards factual knowledge.

> VS 2 has five standards, four of which require the student to be able to "locate" and one to "describe."
>
> VS 3 has seven standards, six of which require the student to be able to "identify" or "describe" and only one requires an explanation."
>
> VS 4 has four standards, two of which require "explanations" and two require the student to be able to "describe."
>
> VS 5 has three standards and they all require identification.

In summary, out of these 21 standards only <u>three</u> require the student to carry out a cognitive task of a higher order than the knowledge level.

The examples given of strategies to teach children cause-and-effect do not actually require analytic thought so much as the ability to connect recalled facts in the correct order. For example, consider the following cause-and-effect table from the VS Enhanced Scope and Sequence document:

Table 1

Cause	Effect
The Virginia Company of London stockholders wanted to establish a colony in America	The colonists chose Jamestown as their settlement site
Jamestown had water deep enough to dock ships and was a good site to defend the settlement from the Spanish	The stockholders asked the king's permission
The Virginia Company of London stockholders asked the king of England for permission to settle a colony in America	The king granted the Virginia Company of London a charter to establish a colony in America

A thoughtful analysis of this table would allow for various links to be made if the exercise were primarily requiring the student to consider and analyze possible cause-and-effect connections. In fact, the "correct" links are largely dependent on the student recalling factual links that have been previously taught. In other words, it is an exercise primarily in recall rather than seeking causal links.

The 20 test items for VS given in Attachment F in the Enhanced Scope and Sequence document of Virginia Studies are all knowledge-based, and none requires any analysis, interpretation, evaluation or the need to generalize (VASoL, Virginia Studies). The same is true of the 2003 Virginia Studies Released Test Items where nine out of ten items are based on recall (VASol, History Assessment).

Passing tests like these does not require flexible, lasting learning. Consider the following passage from Lewis Carroll's "Jabberwocky":

> Twas brillig, and the slithy toves
> Did gyre and gimble in the wabe;
> All mimsy were the borogoves,
> And the mome raths outgrabe.

A knowledge-based multiple-choice test on this piece of poetry might include questions such as these:

The weather in the poem was:
- a) Cloudy
- b) Brillig
- c) Mome
- d) Slithy

Where did the toves gyre?
- a) In the borogoves
- b) Behind the raths
- c) In the wabe
- d) Beside all the mimsy

It is clear that students can answer these kinds of questions even though they have no significant understanding of the content. Their knowledge is inert, not transferable and probably forgotten as soon as the test is over. The ability to answer these questions does draw on a deeper level conceptual structure – the implicit understanding of English grammar – but it does not demonstrate any conceptual understanding of the subject.

The Language of Instruction and Assessment in Science

By contrast, the science curriculum consistently requires higher-order thinking skills. The essential skills are not separated out as they are in Virginia Studies (VASol, Science 5). Instead the *Overview* provides the content and the *Essential Knowledge, Skills, and Processes* provide guidance for the teacher in developing specific curriculum and learning activities. The richness and fascination of science lends itself to inquiry learning where students are actively constructing their own understandings. To attempt to teach it as a set of facts to be remembered is to diminish its ability to develop students as skillful thinkers.

Science students are expected to be active discoverers of knowledge. Consider the following lesson suggestions from the grade 5 Science Enhanced Scope and Sequence document (VASol, Science 5).

> *5.4 Design an investigation to determine how heat affects the states of matter (e.g., water). Include in the design ways information will be recorded, what measures will be made, what instruments will be used, and ways the data will be graphed.*

The student is expected to design an investigation and uncover that *"As its temperature increases, many kinds of matter change from a solid to a liquid to a gas. As its temperature decreases, that matter changes from a gas to a liquid to a solid"* through inquiry and active investigation.

In another lesson investigating the structure and states of matter students are required to determine whether air takes up space. They then form a hypothesis and design an experiment to prove their hypothesis, concluding that all matter takes up space regardless of its state.

In this lesson the teacher begins with a whole-class discussion by asking students whether they believe air takes up space. The preconceptions and prior knowledge of students are revealed and engaged—satisfying Finding One of "How People Learn," above. This inquiry-based lesson provides a learning environment in which students are building for themselves a conceptual framework within which to place their new knowledge – attending to Finding Two of "How People Learn."

An examination of the verbs used in the grade 5 Science Curriculum Framework shows a bias towards the knowledge and comprehension levels of Bloom's taxonomy but also a significant emphasis on the higher-order cognitive skills of synthesis and evaluation that is reflected in the suggested lesson plans in the Enhanced Scope and Sequence document. The distribution of these verbs over Bloom's taxonomy of the cognitive domain is shown in Table 2 and their percentage is reported in Figure 1.

Table 2

	Grade 5 Science verbs
Bloom	**CF Skill**
Knowledge	22
Comprehension	23
Application	5
Analysis	13
Synthesis	13 (create, design, compose)
Evaluation	10 (measure, explain, compare)

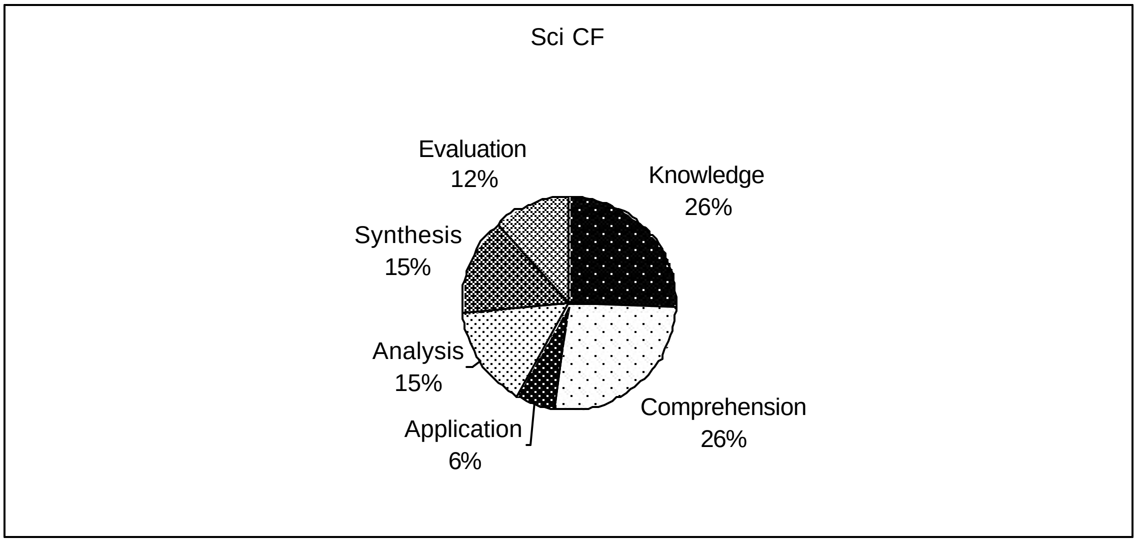

Figure 1. Distribution of cognitive skills (according to Bloom's taxonomy) implicit in the verbs used in the Grade 5 Science Curriculum Framework in Virginia's Standards of Learning.

This comparison between the History and Science educational objectives leads us to conclude that it is important to look closely at the actual learning tasks required of the students in order to discover the required level of thinking. Simply saying that any given curriculum develops higher-order thinking skills doesn't make it so.

Skilled science teachers design lessons that actively involve students in discovery. The lesson samples provided in the Enhanced Scope and Sequence document for grade 5 science incorporate genuine inquiry learning, based on knowledge and comprehension, but incorporating the higher-order cognitive levels of analysis, synthesis and evaluation.

Metacognition

What is missing in these suggested lessons, however, is any structured attention to Finding Three in "How People Learn"—students must learn how to self monitor their learning through metacognition. For effective, lasting learning to take place students must also understand the levels of metacognitive thought. These levels were first developed by David Perkins and Robert Swartz (Swartz, 2001). These require that metacognitive thinkers:

1) be aware of the kinds of thinking they are doing,
2) know the strategies they are using to do the thinking,
3) reflectively evaluate the effectiveness of their thinking and
4) plan how they would do some similar kind thinking in the future

Opportunities for metacognition need to be interwoven into every lesson. An effective technique for this is Think-Aloud Problem Solving (TAPS). Science lessons like the one described provide fertile ground for TAPS where students are invited to:

- describe their plans and strategies for solving the problem,
- share their thinking as they are implementing their plan,
- reflect on/evaluate the effectiveness of their strategy,
- plan the best strategy for the next similar thinking task

These strategies can be incorporated in existing strategies for increasing student's conceptual understanding such as Peer Instruction.

Metacognition is engaged and sustained in science teaching when the teacher (Costa, 2001):

- encourages students to **check for accuracy** by asking students questions such as -
  "How do you know you are right?"
  "What other ways can you prove that you are correct?"

- creates opportunities for students to **clarify** –
  "Explain what you mean when you said 'I just figured it out.'"
  "When you said you started at the beginning, how did you know where to begin?"

- provides data, not answers, when students are on the wrong track or confused –
  "I think you heard it wrong; let me repeat the question."
  "You need to check your observations or data."

- resists making judgments –
  "So, your hypothesis is …...?"
  "Who has a different thought?"

- makes sure students stay focused on thinking –
  "Tell us what strategies you used to solve that problem."

- encourages persistence –
  "I know you can do this. Let's try another approach."

The Next Step

When it is well taught, science is exciting for all students. In Virginia we have a science curriculum that provides ample opportunities for classroom teachers to address the first two key findings of "How People Learn." The next step is to find ways to infuse the third finding, the need to develop metacognitive skills in our students. When we do that, the science classroom will become a rich environment in which we teach the foundational thinking skills and dispositions that support all learning in all disciplines. We will also create life-long, creative and innovative thinkers who will lead our success in the global community.

Appendix

We have examined the distribution of cognitive skills across the elementary school curriculum for grades three and five using Bloom's taxonomy as a basis for assessing the level of cognition.

To examine the tasks associated with the Standards of Learning, we used the bullet points under the Essential Knowledge, Skills, and Processes from the Curriculum Framework documents for the third and fifth grades in the subject areas English (Reading and Writing), Mathematics and Science. In History/Social Studies we have used the Essential Questions because, in our opinion, the Essential Skills do not always reflect the tasks tracked in the Essential Understanding, Questions and Knowledge document. The results of this study are shown in the table below. Since we are interested in comparing the occurrence of higher-level skills we have combined the results for the first three items in Bloom's taxonomy (knowledge, comprehension and application) in one category and the second three (analysis, synthesis and evaluation) in another category.

Table A - 1
Distribution of Cognitive Skills in Tasks Required of 3rd and 5th Grade Students in Virginia (in percentage per subject)

Bloom Categories Subject	Knowledge Comprehension Application	Analysis Synthesis Evaluation
	Grade 5	
English	44	56
Mathematics	68	32
Science	12	88
History	64	36
	Grade 3	
English	56	44
Mathematics	64	36
Science	27	73
History	67	33

Results for both grades show the preponderance of higher order thinking skills in science.

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Using an Unconventional History of the Battery to Engage Students and Explore the Importance of Evidence

Dr. Gregory W. Corder

The discovery of an ancient artifact, called by some the 'Baghdad Battery', has challenged the conventional history of the battery, taking its origin far back into the ancient world. Drawing on such uncertainty, an interdisciplinary approach to teaching about electrochemical batteries is presented, along with a means for conveying the importance of evidence.

Introduction

The historical backgrounds of scientific discovery and technological development are important parts of science education (American Association for the Advancement of Science, 1990). On occasion, however, discoveries of new archeological artifacts can lead to historical evidence that challenges our view of scientific development. One such example has caused many to rethink the early historical record of electrical power sources.

Students are often intrigued with notions of history that do fit within the mainstream, accepted scheme. One interpretation of a 2000-year-old clay vase's purpose has produced an unconventional history of the battery that can provide science educators with an opportunity to engage students. Below, I outline an interdisciplinary approach I have used to capitalize on students' interest, teach them about how batteries work, and convey the bigger idea of the importance of evidence.

Conventional and Unconventional Histories of the Battery

Many science books agree upon a conventional origin of the electrochemical battery. *The Dictionary of Scientific Biography* (Gillispie, 1976), for example, explains that Luigi Galvani discovered in 1791 that a dead frog's muscles contracted when two dissimilar metals (brass and iron) were brought into contact with the muscle and each other. Building on that discovery, Alessandro Volta repeated Galvani's discovery with different metals and animals. Furthermore, Volta discovered that he could reproduce this current outside of living tissue by placing the metals in certain chemical solutions. Then, in 1800, he invented the voltaic pile by stacking metal discs on top of one another and separating them with a moist conductor to produce an electrical current. This became known as the first electric battery. Ultimately, the unit of electrical potential was named the volt, after Volta. This sequence led to a straightforward and widely accepted origin of the electric battery. A discovery in the 1930s, however, has brought into question the timeline of the battery's background, suggesting that its origins may actually be far, far older than they had been thought to be.

German painter and archeologist König (1938), as cited in Eggert (1996) and Dubpernell (1978), reported that an unusual artifact was unearthed near Baghdad, Iraq, in 1936 from the 2000-year-old layer of an ancient Asian culture. He described the artifact as a bright, yellow clay vase about 15 centimeters in height. A cylindrical copper pipe was held fast by asphalt and extended down into the vase. Inside the copper pipe was a completely oxidized iron rod held in place, also by asphalt. The physical and material characteristics of the artifact, later termed the Baghdad Battery, led König to suggest that the artifact was in fact a type of electrochemical battery.

Debate over the “Battery” has ensued among certain academic circles since König’s assertion. More recently, however, it received popular attention in the mainstream media. An episode of the Discovery Channel’s show *Mythbusters* (which aired March 23, 2005) called into question the possibility of the artifact’s application as an electrical device. The show’s cast replicated the artifact and attempted three different applications – electroplating a medallion, relieving pain with acupuncture via electro stimulation, and delivering a shock into a person such that he or she would acknowledge a divine experience. The show concluded that all three applications were “plausible,” but also concluded that such applications were doubtful.

In 1996, the popular journal, *Skeptical Enquirer*, had also allowed for the possibility of the Baghdad Battery’s use as an electrical device, but expressed misgivings. Eggert (1996) explained that an absence of artifacts such as connecting wires, electroplated metals, and written records weaken the claims of the Battery’s purported applications. Moreover, he criticized proponents of the electrical cell argument for not citing sources and/or depending on secondary/tertiary sources. Finally, he considered Gebelein’s (1991) suggestion that the artifact is actually a fertility symbol. He explained that the copper pipe and iron rod are associated with human reproductive organs in “the affair of Venus (in alchemy related to copper) with Mars (related to iron)” (p. 34).

Value to the Classroom

Many students enjoy controversy. The Baghdad Battery presents an interesting opportunity to expose students to the nature of electrochemistry through the examination of this controversy. More broadly, however, it also presents an opportunity to address the very nature of how we understand our past.

State and national standards require that I teach a unit on electricity to my eighth-grade students. Experience and education have taught me the value of integrating other subject areas and connecting the specific content with broader scientific themes.

Over the course of several lessons, my interdisciplinary approach to teaching about the Baghdad Battery incorporates science, history, and language arts. I begin with an activity that illustrates the components of an electrochemical cell. I pair students and present each pair with a large lemon wedge (electrolyte), a zinc nail (anode), a copper tack (cathode), and a low current galvanometer with connecting wires. I challenge students to use the items to make the galvanometer move without touching it (i.e., to produce electricity). I encourage sharing when groups start to experience success. When all pairs have successfully produced electricity, I direct them to reverse the wires on the current meter to see what happens. Finally, I lead a grand discussion to probe their perceptions of their observations.

After the introductory activity, I present students with a laboratory. I give each student pair several different electrolytes (lemon, orange, apple, potato, etc.), electrodes of dissimilar metal cylinders (lead, zinc, copper, steel, etc.), and an inexpensive digital multimeter. Students are directed to identify one (independent) variable that affects the battery's electrical potential (voltage). Finally, I explain that students will be required to present and justify their findings quantitatively. Before they begin, I remind students to avoid coupled variables and to practice good experimental procedures. While students are actively conducting the lab, I assist in experimental technique and multimeters operation. As students interpret their data, they often need help choosing the best way to present their data. When the lab is concluded, students use graphs and tables to report the relationship between their independent variable (electrode depth, electrode separation, electrode material, or electrolyte material) and electrical potential.

After the laboratory, I tell the conventional story of the battery's discovery. I complement the story with pictures of historical artifacts found at a variety of museum websites. During the story, I mention concurrent and notable historic events to give students a broader perspective of the period. If students mention having heard of an ancient battery during my story, I ask them to hold those comments until later. After concluding the story, I explain that an alternative history exists. I present students with a collection of websites that describe the Baghdad Battery. Students spend time reading about the "Battery" and/or looking at some pictures and illustrations. In order to ensure that all students understand the readings, I lead an informal discussion to confirm that students understand the similarities of the Baghdad Battery to the conventional electrochemical battery, as well as the suggested ancient applications. Finally, I direct students to write a fictional story set in ancient times that centers on the use of the Baghdad Battery.

As a beginning teacher, I was more apt to teach the content without raising any big ideas in science. With more experience, I have come to recognize the need to raise the larger ideas and themes in science – in this case, the importance of evidence. The Baghdad Battery offers teachers the opportunity to address such an idea.

In order to lead a discussion on this topic, I draw from my own background as a graduate student. In a research class, I had a professor, Dale Foreman, who frequently stated, "We never prove anything!" His point was that, in truth, nothing is ever "proved," since the best we can do is seek to build a case for our claims, being limited by what we know at any given time. History, like science, relies on evidence. To convey this important concept, I lead a student debate on the authenticity of the Baghdad Battery's use as an electrical device. Students take a position and work together to collect evidence for their case. The debate is often very animated and enjoyable for most students.

Summary

This article has presented a conventional history of the battery that identifies the discoveries of Volta and Galvani. However, König's discovery of the Baghdad Battery and suggestion of its use as an ancient power source has led some scholars to question that history. This article does not seek to discount the possibility that the Baghdad Battery was indeed used for some type of electrical application; however, a lack of evidence leads one to question such assertions. Drawing on that uncertainty, I have outlined an interdisciplinary approach to teaching about the battery and presenting students with the bigger idea of the importance of evidence.

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Overseas Travel Offers Both Students and Teachers Worthwhile Experiences

Debra Duffy

Overseas travel programs for high school students offer unique opportunities to experience different cultures and language, as well as enhance their awareness of the global community. The Nexus Program at Cape Henry Collegiate School has been in operation for four years. It offers unique out-of-the-classroom lessons to broaden the minds of high school students. The key to successful overseas travel with high school students is to be flexible and to keep an open mind to the antics, energies, and curiosities of young people.

Getting Involved

Several years ago I attended the Virginia Community College System Peer Science Conference and found myself sitting in a presentation on overseas travel for college students. During the presentation the speaker outlined the benefits offered to students who could take advantage of these learning experiences outside of the classroom. I watched as pictures of students on glaciers, volcanoes, and in boats on a river somewhere in a tropical jungle appeared on the screen. We had just launched our Nexus Program at Cape Henry Collegiate School in hopes of bringing such opportunities to high school students. After hearing the wonderful experiences the presenter was sharing with the audience, I felt sure that our program would be a success. Then someone in the audience asked if this type of program would work for high school students. The speaker got a sour look on her face and mumbled something about opening Pandora's Box if you ever attempted to take high school students out of the country. That was four years ago, and since then the Nexus program at Cape Henry Collegiate School has grown by leaps and bounds, taking high school students to all corners of the world including Greece, Spain, Italy, Cuba, Vietnam, Bhutan, South Africa and Ecuador.

The goal of Cape Henry's Nexus Program is to "offer students the opportunity to travel overseas and explore diverse cultures, varied ecosystems, or immerse themselves in the language of their choosing in order to create a lifelong yearning for learning and to foster an awareness of the global community." In some cases, students are able to earn high school credit for their experiences. Teachers are encouraged to submit proposals to locations around the world where they would like to take students to study the culture, science, and/or language. When the opportunity arose for an eco-tour of Ecuador, both the mainland and the Galapagos, this science teacher jumped at the chance. Whether Pandora's Box was to be opened or closed, I was going.

The trip was offered to students as a one-trimester science credit that focused on organic evolution and ecosystem functions. The students were given preliminary reading material and met with me for three sessions prior to the trip. As the school year came to a close and most teachers were swapping-out their work shoes for flip-flops and dreaming of sand between their toes, I was making sure I had copies of passports and permission-to-travel forms from rising 10th, 11th and 12th graders, ten teenagers total. Packed in my duffle was a plentiful supply of biodegradable products, boots, bug spay, sun screen, and malaria pills. From Norfolk, Virginia, we departed, ten energetic high school students and two teachers, setting off for two weeks in Ecuador.

San Cristobal: Hands-on Ecology

After one night in the capitol city of Quito, the first leg of the trip landed us on San Cristobal Island in the Galapagos Archipelago. While in San Cristobal, we stayed at the Jutan Sacha biological station. Various maps were provided for students to learn the geology of the volcanic islands, how they had sprung up from the Pacific Ocean floor millions of years ago from a hot spot in the Earth's mantle similar, yet very different from the hot spot that is responsible for the Hawaiian Islands. Students traversed, hiked, and climbed old 'aa' lava flows and they came to the conclusion that natives of these islands, that had to walk on these rocks bare-footed as we had done, must have screamed AH-AH!

Next we focused our attention on the uniqueness of the flora and fauna of these volcanic islands. The islands have provided the foundation for flora and fauna that drifted, dropped, or flew in from afar to grow and develop to a self sufficient ecosystem; an ecosystem that Charles Darwin noted on his stop over during the famous voyage of the HMS *Beagle*. As years passed and people began to immigrate and colonize the islands, slowly the natural ecosystem became disrupted. Exposed to a real world laboratory, students were able to see at first hand what humans can do to an ecosystem when different plants and animals are introduced, and that the introduced species can often out-compete the native species.

The goal of the Jutan Sacha station is to protect the natural ecosystem of the island by planting vanishing native species and removing the invasive species. This is not an easy task, as the station is lacking in sophisticated field equipment. Instead they rely heavily on volunteers to go into the field and manually remove invasive species and replant native and endemic species. Our students got a hearty taste of manual field labor as they helped the station workers and volunteers to plant native plants from seeds that were collected in the field, not bought at Home Depot.

Life at the station did not take long to get used to and I found that teenagers surprisingly adapt very quickly. They did without electricity and cell phones and hot water. They enjoyed fresh fruits and vegetables and practiced their Spanish with the station workers. They met and shared meals with the volunteers from England and New Zealand.

So what did the students like most about this part of the trip? Knowing that the station was making an impact on preserving biodiversity, and that they had in a small way helped to do so, was not the number one factor in their minds. The cute British volunteers at the station, especially the one named Leo according to the girls, was by far the major variable in this equation. The vanishing poisonous green apple tree, a major part of the famous giant tortoise's diet, did not stand a chance against Leo for the attention of the female students.

For almost two decades I have been teaching on both the college and high school level about the adventures of Charles Darwin and his observations made on the Galapagos Islands that helped to formulate his theory of natural selection. On this trip I snorkeled along the same shoreline where Darwin first came ashore in 1835. Far above the chilly waters of the cove where we snorkeled, up on the volcanic cliffs, stood a statue of Charles Darwin to commemorate this first landing. As I looked up at the statue, I imagined Darwin in his dingy rowing ashore with notebook in hand all those years ago. I wondered if the sea lion pups greeted him. They were sure friendly with us as they charged, nipped, and played follow-the-leader. Rumor has it that Darwin had major disagreements with Captain Fitzroy of the *Beagle*. Coming ashore to observe nature must have been a refuge for him. I wondered how this intrepid explorer would have handled traveling with teenagers who kept asking to go back to the dollar bootleg-DVD store again because buying 20 yesterday was not enough. Would we ever get through customs?

That same day, on the way back to the marina, our boat cruised slowly along the shoreline to watch the mating rituals of the great frigate birds. Here the males sit in their neatly constructed nests in the tree tops and puff out their red breast décor to attract a female circling above, each male hoping he will be chosen and each female looking for the perfect mate to father her chicks. I think to myself that this is about the way it goes for most members of the animal kingdom. “Let me see it,” I hear from one of the students. Expecting to see students passing binoculars, I turned and saw instead the passing of i-Pods. Oh well, one too many nests is a little too much for teenagers.

In the Andes: Measuring Our Footprint

On the sixth day of the trip we departed San Cristobal to travel back to the mainland of Ecuador. After a day of shopping in downtown Quito, we journeyed by bus along the Andes Mountains to the cloud forest to spend our next six days at La Hisperia, a family-owned farm and surrounding community that work together to provide goods and services for the benefit of the community. On the farm, students learned about organic farming, the problems with monoculture agriculture, and the adverse effects of using too many pesticides in the environment. In the mornings students awoke to crowing roosters, dressed and walked to the barn to help milk the cows. Not once did I hear them complain about the early rising. In the afternoons, students could ride horses, make coffee and chocolate, and hike. Hikes took us to giant waterfalls that looked like scenes from *Jurassic Park*. One afternoon they witnessed the birth of piglets. If that wasn’t enough, students discovered on their own electrical conductivity. They all held hands and the last student closest touched the electrical fence. There seemed to never be a dull moment on the farm.

At night we put on our jackets, sat around campfires, and discussed our ecological footprint on Earth, talking about how much we consume and how much we waste in our daily lives. Students began to talk about their footprint and reminded each other during each meal not to leave food on their plate because that would increase their footprint size. They talked of other ways to decrease their footprint when they returned home. Shorter showers, ride their bike more, and switch standard light bulbs for florescent bulbs. As a teacher, I was seeing young minds open up pass the boundaries of their own backyard. A tiny seed had been planted.

Back Home: The Students (and I) Reflect

Upon our return, the students happily greeted their parents wearing the Ecuador team shirts they had purchased in Quito after watching Ecuador compete in two World Cup games on a fuzzy TV with rabbit-ear antennae. All happy to be back in the USA, we hugged and said good-bye at the baggage claim. In the days that followed I continued my malaria pills and thought about how much I had enjoyed the experience. I look forward to the next time I teach about ecosystems, biodiversity, and natural selection. I have numerous pictures to use during classroom discussions.

As a final assignment, students were to write a paper that summarized their experiences recorded in their journals and the ecological concepts they learned. As I sat down to read the papers. I was expecting stories of Leo, or sea lions, or electrical fences. Of course I read about those things, but to my delight I also found that students demonstrated an understanding of the ecological concepts that had been emphasized on the trip. It was clear that they had learned that in nature everything is connected and doing one thing to a habitat, such as bringing to an island a familiar plant to enjoy a favorite food, can have rippling effects throughout an ecosystem.

As the new school year began, three enthusiastic students from the trip switched into my AP Environmental Science class. These students have made wonderful contributions to classroom discussions about their experiences in Ecuador. They have led discussions about reducing individual ecological footprints as the class worked through an Internet activity. They have added more insight to our discussions of the impact the poverty has on environmental problems, reflecting on direct observations from small towns in the Andes Mountains that we traveled through. Two of the students have decided to return to the Galapagos to do their senior project at Jutan Sacha in May of this year. In 2008, we hope to run the trip again focusing only on the Galapagos, and to have students participate in more detailed biological observations such as species counts and nesting habits.

So in the long run, what will these students take with them from their Ecuador experience? Will they remember the difference between native and invasive species? Maybe. Will they remember the graceful dance of the sea lions in the water? Probably. Will they try to reduce their ecological footprint? Hopefully. Will they remember Leo? Absolutely. I think the key to taking high school students overseas is to be flexible. Enjoy their energy, playfulness, and adaptability. Don’t be afraid to open the Box, there may be delightful surprises waiting inside.

Debra Duffy teaches several science courses and serves as department chair at Cape Henry Collegiate School in Virginia Beach, where she has worked for nine years. Additionally, she has worked as a wetland geologist and has served as an adjunct professor at several Virginia institutions of higher learning, including Tidewater Community College, Old Dominion University and The College of William and Mary. She will begin work on her Ph.D. in Curriculum and Instruction this spring.

Student-drawn Diagrams and Picture Booklets: A Key to SOL Success in Science

Dan Johnson

Action Research in a variety of science classrooms indicates that when students are asked to draw some aspect of what they are learning, they perform better on a variety of assessments. Many opportunities exist for such student-drawn diagrams and picture booklets.

Responding to a Visual Culture

Many students are visual learners. Even those students whose primary learning style is non-visual often develop strong mental ties between visual information and memory because our culture is saturated by visual imagery through TV, DVDs movies, music videos and video games.

Responding to this reality, I often incorporate visual activities into my teaching. I have conducted an informal study of my teaching methods to determine what learning activities result in the best student performance. Providing students with opportunities to engage visually yields very positive results. The average success rate for quiz/test questions that were taught without any visual component is 74%. The average success rate for questions that were taught using diagrams or picture booklets is 93%. The percentages of student retention of facts/concepts taught using the student-drawn graphics technique have remained steadily high for the past 5 years (+ or – 3%) for all my students from advanced classes to students in at-risk categories.

I was surprised to learn that this success rate even exceeded the success rate of facts/concepts taught in lecture/notes format that were reinforced by hands-on labs. The success rate for questions relating to hands-on labs fluctuated wildly from 47% to 93% with an overall average of 79%. I believe that three factors contributed to this fluctuation. First the instructional quality of the labs themselves: some labs, although interesting to the students, don't do a good job of enhancing their retention of the facts or concepts being demonstrated. The second factor is what I call the fun factor: sometimes the students are having so much fun doing the lab they miss the whole point of what the lab is demonstrating. The final factor in lab effectiveness is time: I have taught 90-minute blocks and several variations of modified blocks ranging from 47 minutes to 65 minutes and have found that there must be enough time after the lab is done and cleaned up to allow for group discussion to help re-focus the students on the objectives of the lab in order to improve retention.

My Action Research

I have kept track of how I taught different science facts and concepts for more than 10 years. I conducted this study in an informal manner solely to improve myself as a teacher not for publication. For each item I assessed, I picked specific objectives that were not likely to be known by my students prior to the lesson (such as how Doppler radar works or the percentages of the sun's radiant energy absorbed by the atmosphere, etc.). I would then teach the information using a variety of different teaching techniques during different units and different school years. I used teaching formats such as student-written notes during lecture, fill-in-the-blank sheets during lecture, some form of video presentation, a hands-on laboratory, and different combinations of these and other activities. I selected different specific facts or processes that I would keep track of for each of the different subjects I taught. After a few years I began to see that using student-drawn graphics as a tool had a significant impact on student retention, so I have steadily increased the amount of material I present in this manner.

I then compared how the information was taught with what percentage of students were successful (got the correct answer) on the test or quiz questions that covered those specific facts or concepts. Using the example of how Doppler radar works I would then ask questions such as "The movement of an object will cause what to change in the radar return?" on a test or quiz. Students who answered that the frequency of the returning radio wave will shift up for objects moving toward the radar and down for objects moving away from the radar would be counted as successfully learning the material taught. I used a variety of question styles to determine student success, including multiple choice, fill-in-the-blank, and essay formats (the results remained relatively constant regardless of question format). I taught about 100 students each year and have taught life science, physical science and earth science courses during this period. I have kept informal records of the percentage of students who answered the quiz/test questions corresponding to the lesson taught using the various methods of instruction. I have found that the greatest student success has been achieved for facts/concepts that I taught by including some form of student-drawn visual aid.

In addition to my own experience in the classroom, an evaluation of released SOL test items reveals that a large percentage of the questions on the Science 8 and Earth Science SOL tests involve some sort of picture, graph, or diagram. I have not personally checked out the other science SOL tests, but my colleagues inform me that many questions on all science SOL tests involve some form of picture, graph or diagram.

My Research Applied

Information about successful teaching techniques without practical examples is useless to me, so I will share the application of this concept by relating how I learned how to use it successfully. I first learned the value of student-drawn diagrams and picture books from some wonderful experienced teachers when I first began teaching. Mr. Les Deane at Chickahominy Middle School, in Hanover County, shared how he had students make themed booklets for the different forms of energy taught in the physical science curriculum. He showed me how to use the diagrams and drawings in our text book with brief captions he developed to bring out the important information in the diagram. He also included definitions of key terms on the pages with diagrams related to them.

As an example, in the "Light Booklet" the students would copy a diagram of the color rainbow and write a caption that explained that each color represented a different frequency of light and that the memory aid of ROY G. BIV provided the colors in order of frequency from lowest frequency to highest frequency. Students would also copy a diagram showing the relationship between frequency and wavelength from the textbook and write a caption that explained the inverse relationship between them. Next, the students would draw a diagram of how a prism worked with a caption that combined the two previous concepts together to explain why the red light gets bent more than the higher frequencies of light. The students would then draw diagrams showing how the light is refracted (bent) by concave and convex lenses showing what happens to the image in both cases. Diagrams would address the concept of reflection and mirrors to show how the image is inverted. A page devoted to infrared and ultraviolet light would be included. Les would have his students make similar booklets for the other forms of energy taught in the 8th grade curriculum. As all good teachers do, I stole his method and personalized it to my teaching style, as other teachers can.

I learned the value of making diagrams of cycles from Mr. Kelly Hedgepeth at Henderson Middle School in Richmond. Kelly would have his students make large diagrams of natural cycles in life Sscience using the large 11x17 paper you can buy at any office supply store. (Your school may even have a supply that isn't being utilized because it is the largest size most copy machines can handle.) Kelly used large block arrows with space inside for the student to write what was changing and what caused the change between each state in the cycle. I have used this concept to help my students understand what happens and why during various cycles in earth science, physical science and life science.

I have adapted the concept of drawing as a teaching tool to many different situations and now use this method of presenting information whenever I can. For example, I use it to show how the Principle of Superposition can be used to determine the approximate (relative) age of a fossil in a diagram of layers of the earth for earth science. First, I have the students copy a diagram of the geologic timeline from their text book which shows the development of different creatures in each era and have them draw a picture (often crude) of the creatures present in each era. The next day, I draw two different diagrams on the board showing the geologic layers beneath the soil with different fossils or other clues labeled with letters in different layers. Then I uncover one diagram and ask them questions like, "What geologic era could fossil 'A' have been formed in?" Then we talk through it as a class using the facts we know about the creatures that existed in different geologic eras using the timelines they made in class the day before to determine the possible correct answers. Then, I uncover the second diagram and have the students copy it onto a piece of poster paper. I have the students develop their own questions for the second diagram and then ask the class. We then discuss the possible answers to each of their questions. The next day I have one diagram drawn on the board and I give them a quiz which requires them to interpret the diagram to answer the questions. Then on the chapter test I will ask multiple choice or essay questions that require the students to recall the facts they used to answer the diagram questions. I will ask a question such as, "Mammals first appeared during which geologic era?"

I now use "Poster Labs" to teach and reinforce almost every "critical knowledge" in the middle school SOL guidelines. Before I teach each new unit, I look at all the graphics available in the textbook and other classroom materials to see if they accurately cover the facts or concepts being taught. Then I use them as is or modify them, if necessary, to teach the objectives of the lesson. Each student gets a sheet of 11x17 paper, a pencil, and something to color with. I keep a supply of markers, crayons, and colored pencils for the students to pick from as I have found different students prefer different methods to color their posters. I assign a diagram or two from the text book for them to copy. I choose only diagrams that portray the concept or idea clearly and are well labeled. If I can't find a book diagram that covers the material clearly or completely, I draw one on the board for them to copy. I usually allow them 15 - 40 minutes to copy the diagram and then color it. I collect the posters at the end of the class and grade them for a lab grade.

I grade only information, not the quality of the artwork. If there are 10 pieces of information on the diagram, I assign each 10 points, if twenty then 5 points, etc. All arrows must be labeled, the caption (if used) must be copied completely, and all the parts of the diagram must be present. After grading and returning to the students, I ask students whose diagrams earned an "A" to let me laminate them for display in the room. It amazes me how creative the students can be in their posters.

I start the school year with posters from previous years on the walls and then replace them with this year's work as we progress through the year. The students love to see their picture with a big "A" on it displayed on the walls of the classroom. They often visit my room during the first week of the next school year to see which posters I selected to start the year off with.

The lists that follow provide a few examples I have used successfully in each of the subjects I have taught that are great places to use student-drawn graphics:

Life Science	**Physical Science**	**Earth Science**
cell organelles	phases of matter	rock cycle
plant/animal cells	properties of metals	weathering & erosion
cell processes	types of reactions	mineral tests
cell division	properties of acids/bases	geologic timeline
chromosomes/DNA	parts of atom	global wind patterns
biomes	element/compound	global currents
ecosystems	wave action/parts of wave	layers of the earth
habitats	sound & sonar	layers of the atmosphere
adaptations	nuclear reactions	layers of the ocean
water cycle	heat/molecular motion	parts of a volcano
nitrogen cycle	gravity/terminal velocity	how lightning forms
pollution sources	motion of planets	lifecycle of a star

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Student-Led Demonstrations: How and Why

James W. Laughner

Chemistry demonstrations normally performed by teachers were converted into student-led and student-performed demonstrations with teacher-initiated Socratic dialogue. Students were given a set of directions which was read by one student to the class, then re-read as a second student performed the actions and all students recorded observations. Over two years, it was noted that content retention, student participation, and affective outcomes were enhanced when students themselves did demonstrations.

Introduction

A major trend in science teaching has been the move toward active student involvement with scientific materials. Educational studies (Bredderman, 1982; Stokstad, 2001) have shown benefits to "hands-on" work, which has become even more important as students become less experienced with tools and manual activity outside of school.

I became a high school science teacher in 1982 after a career as an engineer and professor of engineering. I taught under a mentor (Raymond Miller, Ed.D., since deceased), and he taught me the value of having students perform science demonstrations themselves. I have come to agree with Dr. Miller that teacher-led demonstrations are often only a show, while student-led demonstrations are part of a better learning environment.

At that time I taught chemistry and physics, and felt that the demonstrations explained and performed by teachers were less effective than Dr. Miller's demonstrations that actively involved students. Therefore, I frequently had students perform chemistry demonstrations. In so doing, I rewrote many demonstrations to allow students to perform them safely and easily.

Upon moving to a new school, I found that logistics (classroom sharing, team teaching, etc.) prohibited student-performed chemistry demonstrations. In chemistry, a required course for all students, I noticed a lack of interest among the students for the course. I suspected that student-led demonstrations would address this lack of interest and perhaps improve academic performance as well.

The following year I was allowed to resume student demonstrations in all my science classes. Records of student attitudes toward the class and academic performance records indicated significant improvements during my second year, the year I introduced student-led demonstrations. I feel that student-performed demonstrations were a major reason for the improvements.

Definition of and Purposes of Demonstrations

Demonstrations serve at least three distinct pedagogical purposes. First, a demonstration may provide a "discrepant event" for the students to consider as they realize the need to construct new mental schema about what they are studying (Brungardt, 1994; Macbeth, 2000; Misiti, 2000). Second, a demonstration may be performed to confirm the expectations of the student or assess student learning (Radford, 1995). This type of demonstration is often an ideal, anecdotal model of the concept, thereby helping the student retain or interpret the concept correctly. Third, the demonstration can be used to explain a correct procedure, for example, how to use a lever.

All three types of demonstrations are usually instructor-led. The most common student-performed (though still teacher-led or even worksheet-led) activity is the "laboratory experiment." This term is a misnomer since most "labs" are actually student-performed concept demonstrations (O'Brien, 1991) rather than true scientific experiments. Using this common, shorthand, but confusing language, my action research could be viewed as rewriting "demos" so they may be performed as "group labs." Teacher-performed demonstrations have several problems:

1. "Discrepant event demonstrations" often are showy, even "magical" presentations. Students may be involved and excited as spectators instead of learners. In addition, an instructor's attention may be diverted from the pedagogical to the theatric. The activities should be changed so that students "run the show" (Lopez-Garcia, 1997).
2. "Confirming event demonstrations" often become illustrated lectures. Student input and thought may not be stimulated, in spite of the use of manipulatives.
3. "Procedural demonstrations" take no advantage of tactile learning, and seldom even require note taking, since the procedure is often described in a lab manual.

Improving Demonstrations through Student Performance

I have attempted to improve all three types of demonstration, with some success. Two specific improvements have already been mentioned in the literature:

1. Students perform discrepant events for others, or participate with the teacher (Galus, 2000).
2. Socratic questioning involves the students directly, with predictions often written down to enhance memory or emphasize a discrepant event. This is sometimes called the "inquiry" method for demonstrations (Penick, 1991; Chiappetta, 1997).

I decided to use these two ideas during my year of action research, and added two more:

1. Students often need help in reading and in interpreting oral and written instructions. So I had one student read the instructions carefully, once to the whole class and then again while a second student actually performed the actions.
2. Partly to develop writing skills and partly to keep observers on task, I required all students to take notes and write narratives about the demonstrations (Ruck, 1991). These notes almost always included:
   - a sketch of the apparatus;
   - a list of the chemicals and equipment;
   - a hypothesis of what might happen, written before the actual demonstration;
   - a description of what was seen during the demonstration;
   - an explanation describing what happened in "scientific language."

Positive Pedagogical Outcomes of the Experiment

I observed many positive effects upon changing to student-performed demonstrations. Two of the most obvious, the increase in retention and the improvement in attitude toward science, were quantitatively verified by the end-of-year test and by an attitude survey taken annually. Of course, my attitude was better as well, partly because I noticed other positive outcomes the second year, which may have had an impact on student attitudes.

Students became more willing to ask questions during student-performed demonstrations. They took notes much more willingly (notes were checked and credit given, of course). Students began to make connections between concepts and observations more frequently, with less teacher direction. Students' confidence in their abilities to independently follow written instructions increased.

There was no longer a need to distinguish among the three purposes of demonstration. The students took notes in all cases. Therefore, if the demonstration was procedural, they had quite thorough observational notes that became part of their procedure for an upcoming lab. If the demonstration was either discrepant or confirming, the students usually figured that out for themselves, although I occasionally injected Socratic questions. I believe the better the design of student-performed demonstrations the less likely I was to inject any questions or instructions—ideally, Socratic questioning became "student-directed" as well!

Procedure for student-performed demonstration preparation and performance

Although student-performed demonstrations were often used to start a class, they could be used anytime during the lesson (once students were familiar with the procedure). Demonstrations of this type can fit into many types of lesson design—see 5E Learning Cycle design (Hitt, 2005) for a specific example of this type of lesson with included demonstrations.

My procedure for constructing student-performed demonstrations is detailed below. I encourage other teachers to test and modify the procedure, and would be happy to share specific examples.

1. Select a demonstration addressing an upcoming topic.
2. Simplify the procedure for student performance and/or greater safety. Follow guidelines for safe practice (see Freedman, 2000) and have any changes checked by a qualified colleague.
3. Write a set of simple-to-read but very clear and detailed instructions on one page.
4. Test the modified demonstration a week before using it; rewrite and retest it as necessary.
5. Test the demonstration again with a student performing it under close supervision and rewrite if necessary.
6. Assign a reading relevant to the topic and the demonstration the day before the demonstration, if one can be found.
7. On the day of the demonstration, prepare all materials. Start the demonstration, preferably early in the class, following these steps:
    - Randomly select one student to read the instructions and one to perform the demonstration.
    - Remind all students to take a page of notes, and encourage sketching.
    - Have the reader read the instructions slowly. Note takers may listen, identify objects mentioned, sketch, or ask questions.
    - During the second reading, the performer follows the instructions. Students may ask questions or comment. The teacher should allow students to guide the process as much as possible, only speaking if the students do not follow directions or safe practice, or if a crucial observation may be missed.
    - Students may suggest changes ("What would happen if…?"). Repeating the experiment with the changes empowers the students, but the teacher must be sure that the change is safe.
    - After the demonstration, students should discuss what they are writing in their notes about their observations.

Conclusion

Student-performed demonstrations are a positive change in educational methodology. Attitudes, note-taking ability, attention span, retention, and ability to follow directions appear to be enhanced by the change from teacher-led to student-led demonstrations.

Appendix 1

Student-led Physics Demonstration Number 1:
Shortening a Pendulum

Reader: Read directions slowly the first time.
Class members: Take notes; make drawings.
Student volunteer: Assemble the equipment.

Reader: re-read the directions while the volunteer does the demonstration.
Directions:

1. Tie the mass to the one meter long string.
2. Hold the string vertically, grasping the top with the mass at the bottom.
3. Pull the mass back about a decimeter and let go.
4. Let the mass swing for a few seconds while the class watches.
5. While the mass keeps swinging, grab the string about a third of the way down, hold it fast and let the mass keep swinging.
6. Repeat step 5, again grabbing the string partway down.
7. Repeat again and again, grabbing the string closer to the mass each time, and letting the mass swing a few times in between grabs.

Appendix 2

Student-led Physics Demonstration Number 3:
Slowing to a Stop

Reader: When reading directions the first time, include the parenthetical statements.
Class members: Take notes.
Student volunteers: Position the equipment. Practice (some) steps ahead of time.

Reader: re-read the directions without the parenthetical instructions as the demo is done.

Directions:

1. Put the cart on the floor and line it up so it can travel across the front of the room without hitting anything. (Push the cart to one side of the room, then the other, to show it is aligned.)
2. Leave the cart at one side of the front of the room.
3. First volunteer sits on the cart, with five beanbags or blocks of wood ready.
4. Second volunteer stands behind the seated student, hands holding the shoulders of the seated student. (Stop here while all class members sketch this starting setup—stick figures are ok.)
5. The class will watch the clock and when the hand reaches 12 or 6 they count one number each second like this: “3, 2, 1, 0, 1, 2, 3, 4.” (Practice now under teacher guidance and approval.)
6. When the class first says ONE, the pusher will push the cart, accelerating it quickly up to a safe speed. (Practice now; teacher will advise on speed.)

7. When the class says “0,” the pusher begins to smoothly slow the cart by holding back on the rider’s shoulders. The cart should slow until it stops completely after the count of “4.” It should travel most of the way across the room.
8. The rider places a bag or block on the floor *exactly* when the class says each number from 0 to 4, placing a total of five blocks. (Practice)
9. Steps 6-9 can be repeated until the class agrees that every block was placed right when they said a number. Five blocks total. (Each observing student may sketch a hypothesis of what the block spacing will look like.)
10. All class members should sketch the block locations after the run.
11. The rider of the cart now measures the separation between each pair of blocks.
12. Later we will mark the direction of *velocity, acceleration* and make *graphs (d, v, and a* vs. *t)* of this trip, so make sure all of the data is recorded with the sketch.

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A Comparative Study of Chemistry Education in China and the United States

PinPin Peng
Juanita Jo Matkins

There are marked differences and similarities between the way chemistry is studied in China and the United States. Comparisons of education goals, curriculum and textbooks, chemistry teacher profiles, classroom teaching methods and learning approaches, and chemistry lab activities show the strengths and weaknesses of chemistry education in each country, as well as, exposing the possible challenges facing current inquiry-based reform efforts in both countries. The authors believe that through international mutual investigation, Chinese educators and American educators can learn from each other to accelerate the process of achieving their education goals.

Introduction

Chemistry education in China and the United States has a long history. In the past 50 years, both nations experienced similar transitions from an “elite” orientation to a “future-citizenry” orientation, and then to the current inquiry-based education reform. Though chemistry education in China and in the United States shares a lot of similarities, each country’s approach also has its own unique characteristics because of the different education systems and cultural traditions. Since the 1990s, much effort has been put into international comparative studies about Chinese and American students’ science performance, but researchers found that these test score comparisons often failed to explain the complexity and differences in science education between these two countries (Su, Goldstein, & Su, 1995). In the early 1990s, several groups of Chinese science teacher educators visited the United States. These teachers’ reflections on their own experiences in the United States and the results of surveys they completed offered researchers much information about science education in China and the United States through a comparative perspective. Fifteen years later, especially after an interest in inquiry-based teaching and learning in science education emerged, a lot of changes have taken place in high school chemistry classrooms in both China and the United States.

This article mainly explores and compares current Chinese and American chemistry education from the aspects of education goals, curriculum and textbooks, chemistry teacher profiles, classroom teaching methods and learning approaches, and chemistry lab activities. The existing strengths and weaknesses of chemistry education in these two nations, and the possible challenges facing current inquiry-based education reform in China and the United States are also discussed in this article. A literature review of prior studies in addition to the authors’ personal teaching and learning experiences in China and in the United States are the main resources for this article. Some findings and conclusions in this article may therefore need to be validated and supplemented by further research.

Chemistry Education Goals

From the 1950s to the 1980s (excepting the upheavals caused by China's Cultural Revolution from 1966-1976), the general goal of chemistry education in China and in the United States changed from "education for elite: future academic chemists" to "education for all: future citizens." Since the mid-1980s, the goal of chemistry education in China has been recognized as: "to prepare students for higher education and to train skilled personnel for the workplace" (Su et al. 1995). This goal served the educational and social circumstances of that time, because in the 1990s only about half of Chinese high school graduates who passed the National College Entrance Examination would get into colleges, and the other half would go into the workplace. In the autumn of 2001, the Ministry of Education of China proclaimed the second reform of school curriculum structure in order to fully promote high quality education (grades 1-12) with the focus on "training future citizens with a spirit of creativity and practical ability for the 21st century." In this curriculum reform, the goal of chemistry education has been switched from the presumption that students will "master basic chemistry theories and skills" to a system designed to "promote students' scientific literacy and help students build the connection of chemistry, society and their lives."

In contrast to the uniform and focused goal of chemistry education of Chinese schools, American schools did not share a uniform set of goals before 1985 (Su et al. 1995). In the classroom, most individual teachers developed their own goals and expectations for learning. Some American schools had similar goals to those of Chinese schools: to prepare for the next level of education and to prepare for the job market (cited in Su et al., 1995). Some other goals promoted developing habits of inquiry, exploring the interrelationships among living things, interpreting environmental changes, and understanding the nature of science (Goodlad, 1984). In 1985, the U.S. government established a national science education reform project, Project 2061. In this project, U.S. educators proposed a slogan for science education: "all students should achieve scientific literacy." Subsequently the National Science Education Standards (1996) established unified standards for all subjects and grade levels. In 2003, the Virginia Standards of Learning (SOL) set five chemistry standards for public schools. Meanwhile, in 2002, China's Ministry of Education enacted its own national science education project, Project 2049, which is used to guide and supplement the reform of new school curriculum structure in science (Dai, & Xie, 2004). Many Chinese scientists and educators think Chinese Project 2049 was inspired by the U.S. Project 2061.

Though the United States and China share some similarities in education goals, these two education systems still have big differences in the orientation of their education goals (see Figure 1). In America's Project 2061, the goals call for all high school graduates to understand how the scientific endeavor works, as well as what science, math, and technology are like and how they are related to one another. Besides that, students should also be able to understand the relationship between the nature of science and its connections to human beings (Ogens, 1991). This goal is “science literacy oriented” and it focuses on the connections among science, history, humans and the world. On the contrary, in China’s Project 2049, the goal of science education is more focused on knowledge of science: all future citizens should be able to understand basic scientific concepts and knowledge, master essential scientific methods and skills, and process scientific attitudes and values. This goal is “scientific knowledge oriented,” and it focuses on seeking mastery of external scientific knowledge and practical scientific skills (Su et al. 1995).

Chemistry Curriculum

In China, because chemistry is one important subject of the High School Entrance Examination and the National College Entrance Examination, students begin learning chemistry as an independent subject in grade 9, which is the last year of middle school. Because China’s elementary and middle schools belong to the nine-year compulsory education system, all Chinese students are required to take at least one year of chemistry. The Chinese grade 9 chemistry curriculum includes basic inorganic chemistry and rudimentary organic chemistry. Figure 2 is the 9th grade class calendar in Yangzhou University Affiliated Middle School, which is a high-quality middle school in the southeast of China. From the calendar we can see that 9th grade students in this middle school take one chemistry class (45 minutes) every school day for a full school year. Therefore, the time Chinese grade 9/middle school students spend on chemistry is almost the same as the time American high school students spent on general chemistry in high school.

Most students in urban areas of China will go to high school (grade 10-12) after ninth grade. All Chinese high schools share the same chemistry curriculum, which is designed by the Ministry of Education. The main reason for using a unified curriculum nationwide is to allow students to prepare for the National College Entrance Examination. When students get into high school, they take one year of higher level inorganic chemistry class in grade 10. Figure 3 is the 10th grade class calendar in Yangzhou University Affiliated High School. Ordinarily, 10th grade students take 3-4 chemistry classes every week in this high school. Chinese students can choose a science track or arts track when they get into grade 11. No matter which track they choose, every student still has to take chemistry class in grades 11 and 12, but students on the arts track only learn about half the amount of chemistry content that the students on the science track would learn. Some educators state that Chinese secondary school students spend an average of about 500 hours studying chemistry, while American secondary school students who take only one chemistry class spend 180 hours studying chemistry (Su et al., 1995).

Figure1: Class calendar of grade 9 in Yangzhou University Affiliated Middle School, China

Class	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
1	Math	Math	Math	Lang. Arts	Math
2	Chemistry	English	Chemistry	Lang. Arts	English
3	Physics	Chemistry	Physical Ed.	Chemistry	Math
4	Chemistry	Soc. Studies	Lang. Arts	Math	Physics
Lunch Period					
5	Lang. Arts	Physics	English	English	Lang. Arts
6	Physical Ed.	Physics	English	Soc. Studies	Lang. Arts
7	English	Art	History	Music	History
8	Moral Ed.	Outdoor Games	Health Ed.	Outdoor Games	

Though American students spend significantly less time studying chemistry, they are able to take more science courses than their Chinese peers, such as life science, earth science, field biology and so on. Furthermore, in American schools, the science courses are interdisciplinary oriented, allowing students to develop their own interests and talents in science.

In most American high schools, chemistry offerings include general chemistry and Advanced Placement (AP) chemistry. American students take general chemistry in grade 10 or 11. About 10% of American high school students take AP Chemistry in grade 11 or 12. Since chemistry is one of the statewide standard test subjects, most states have their own state chemistry curriculum.

For example, in Virginia, the chemistry curriculum framework (for general chemistry) is similar to the Chinese high school chemistry curriculum. It includes scientific inquiry, chemistry knowledge, and basic skills. However, organic chemistry is not included in the Virginia chemistry curriculum. When examining the Virginia chemistry learning standards (curriculum framework), we found that the Virginia chemistry curriculum emphasizes classic laws and basic principles, and the mathematical method is one of the critical learning approaches required for students by the curriculum. Among the thirty-seven key concepts of the Virginia chemistry framework, about half of these concepts are related to basic laws or principles, and twenty concepts are involved with mathematic calculation (*Science Standards of Learning*, 2003). In contrast, the Chinese high school chemistry curriculum is based on properties of substances and chemical phenomena, and the memorizing method is one of the critical learning approaches required by the curriculum.

One example of this significant difference can be seen by comparing how a gas mixture problem is handled in each system. American high school students may be asked to calculate the partial pressure of each gas component of the gas mixture by using given total pressure and mole percentages. Chinese students, however, will be required to identify the gas components by using given information about the phenomena when the gas mixture reacts with other chemical. The chemical reaction phenomena remembered by Chinese students can help them to solve this problem. In addition to the difference in learning approaches, Chinese chemistry curriculum does not address the nature of science, which is an important component of the American chemistry curriculum.

Figure 2: Class calendar of grade 10 in Yangzhou University Affiliated High School, China

Class	Monday	Tuesday	Wednesday	Thursday	Friday
1	Lang. Arts	Math	English	Chemistry	Math
2	English	English	Lang. Arts	Math	Physics
3	Physical Ed.	Lang. Arts	Math	Biology	Chemistry
4	Biology	History	Geography	Physics	English
Lunch Period					
5	Math	Computer Science	Physics	Soc. Studies	Art
6	Physics	Computer Science	Physical Ed.	English	Lang. Arts
7	Soc. Studies	Chemistry	Chemistry	Outdoor Games	Lang. Arts
8	Moral Ed.	Geography	Elective	History	Outdoor Games

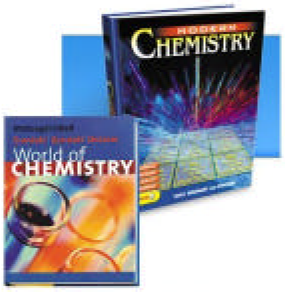
Comparing the general breadth of the curricula, Chinese students learn much more than their American counterparts. The extra content Chinese students learn is the properties of chemicals and organic chemistry. In terms of curriculum depth, many prior studies concluded that American chemistry courses were very general and introductory, with the depth of knowledge much lower than the Chinese chemistry courses (Su, Su, & Goldstein, 1994). Through our comparisons and personal teaching experiences, however, we found this is not true. Choosing the same components of the curriculum, such as the “chemical reactions,” “atomic structure,” or the “gas law,” the American chemistry curriculum provides almost the same depth as the Chinese curriculum on these topics. Furthermore, for some other topics, such as “the electrons in atoms” and “chemical bonds,” the American curriculum even covers higher level knowledge than the Chinese curriculum.

Chemistry Textbooks

In the United States, there is no single textbook used in all schools. Publishing companies issue a variety of chemistry textbooks, hoping to sell them to large school systems. In Virginia, the prevalent chemistry textbooks used in high school are *Modern Chemistry* published by Holt, Rinehart and Winston, *World of Chemistry* published by McDougal Littell and *Chemistry* published by Prentice Hall. Public schools in the United States base their decisions on what textbook to purchase on a number of criteria, with many selecting from books approved by their local or state school boards. In Virginia, the Department of Education selects a set of textbooks that go on the approved list, and school boards choose from this list.

In China, on the other hand, the Ministry of Education issues the national chemistry curriculum syllabus, and the Textbook Committee in the Ministry of Education designates People’s Education Press, which is the biggest and most authoritative textbook publishing company in China, to create the appropriate textbook. The current chemistry textbooks used in major Chinese middle and high schools are *Chemistry, volumes 1-4*, which were published in 2003. Compared to the textbooks used ten years ago, the design of current Chinese chemistry textbooks is much livelier, with many pictures and cartoons having been added to the books.

Chinese chemistry textbooks
(about 200 pp. each)



American chemistry textbooks
(about 1000 pp. each)

Comparing the layout of chemistry textbooks between China and the United States, Chinese textbooks seem easier for students to use. First, the size (21cm x 28cm) and the thickness (less than 200 pages) of each volume of Chinese chemistry textbooks are smaller than the American chemistry textbooks, so it is easier for students to carry and hold. Second, the font size and the line spacing of Chinese textbooks are much bigger, so the textbook is easier for students to read, especially students having visual problems. Furthermore, on each page of the Chinese textbook, there is a margin with one third of the page size for students to take notes, draw pictures or write down some important information, thus students can review their notes as they review the textbooks.

Comparing the content of the chemistry textbooks, the American chemistry textbooks are more comprehensive and advanced than the Chinese textbooks. In the American chemistry textbooks, knowledge is organized in a scientific way, and they provide students with a lot of information about new science and technology, and a stronger connection between chemistry and the students' daily life. From the content of the textbooks, American students should learn much more advanced chemistry knowledge than their Chinese counterparts. However, the reality is quite the contrary. One obvious reason is that American students study only one semester of chemistry for 4×4 block schedule, or one year of chemistry for 8×8 period schedule, and most chemistry teachers use the textbook as a reference source, just picking up the content in the textbook that follows the curriculum standards to teach. Another reason is that American chemistry textbooks are too comprehensive and advanced, and they don't match the skills and abilities of the majority of students in high school. Most American high school students struggle to read the chemistry textbook independently. Chavkin (1997) found in her research that 80% of state-adopted high school chemistry textbooks are beyond high school students' reading ability.

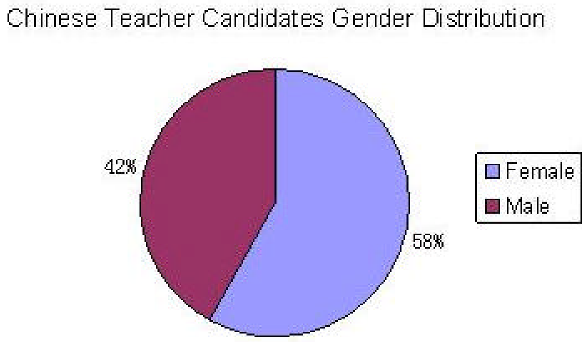
In China, all public schools use the same chemistry textbooks, and the textbooks function as the central pillar for chemistry lessons, rather than as an occasional reference as often happens in the United States (Wang et al. 1996). Chinese chemistry teachers design their lesson plans according to the textbook. The content in all four volumes of chemistry textbooks will be covered in the National College Entrance Exam, so teachers do not dare to add or skip chapters of a text.

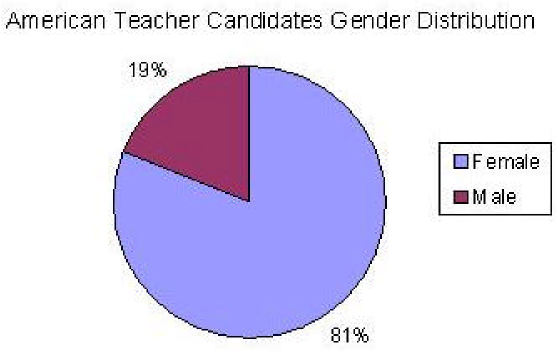
This uniform use of the same textbooks also has its disadvantages. The distribution of educational resources and quality in China is very uneven. Students in urban areas generally receive high quality education and can access more resources than the students in rural areas. Therefore, the unified textbook cannot satisfy the learning needs of students in big cities, and those students need more advanced textbooks with more information about new technologies and new science. On the other hand, in the rural areas some schools even do not have even basic lab facilities for the teacher and students to do the basic experiments on the textbooks. Recently, this situation has been changed. In 2004, People's Education Press published a set of new chemistry textbooks, which are in use in some schools in China's big cities. This set of textbooks is full-color and contains seven different volumes. Each volume presents a topic about chemistry and society, such as Chemistry and Life, Chemistry and Technology, Structure and Characteristics, Organic Chemistry, etc. Furthermore, the schools in the rural areas have been given leeway to choose how the textbooks are used depending on available resources.

Comparison of Profiles of Chemistry Teachers

Chinese chemistry teachers mostly graduate from normal colleges with at least four years of full-time study of chemistry and related teaching skills. Compared to their American counterparts, Chinese chemistry teachers have more comprehensive content knowledge, but less systematic pedagogical knowledge. An undergraduate chemistry education background with a state teacher's license is a strict criterion for a school when selecting a chemistry teacher, and it is almost impossible for a person in China to switch to teaching from another profession. Thus, Chinese chemistry teachers share very similar backgrounds. On the contrary, in the United States, high school chemistry teachers come from diverse education backgrounds. In the state of Virginia, if a person has 38 college chemistry credit hours and 16 non-chemistry science credit hours, in addition to 400 student teaching hours, that person can apply for the Virginia chemistry teacher license and be employed as a chemistry teacher. It is not unusual for a chemistry teacher in the United States to be a former industrial chemist, or even a chemical engineer. In China, the teacher's license has no specific endorsement, and the only criterion for applying for a teacher's license in China is an undergraduate education degree from a nationally accredited college.

Most American chemistry teachers are women. I taught chemistry in two American high schools in Virginia, and I was really surprised by the gender ratio of science teachers. In one high school's science department, there were one male teacher and six or seven female teachers, and in another high school, there were two male science teachers and eight female science teachers. In China, the percentage of male teachers is higher than in the United States. A study of two thousand Chinese teacher candidates conducted in 1996 across China shows that 42% of them were male, in comparison to only 19% males among three thousand U. S. teacher candidates surveyed in the Study of the Education of Educators (Su, Hawkins, Huang, & Zhao, 2001). In addition, there are even more male chemistry teachers in Chinese high schools, which results from the fact that in Chinese high schools more boys choose the science track than girls, and thus more male high school graduates get into the science education program in college.





In both China and the United States teachers work hard. In the United States, a full-time chemistry teacher teaches six classes (45 minutes per class), or three blocks (90 minutes per block) every day. In China, a chemistry teacher usually teaches 3-4 classes (45 minutes per class) every day, but their total work load is greater than this. For example, the grading work is very heavy for Chinese teachers because of the large class size. Furthermore, Chinese high school teachers have to spend 6-8 extra hours each week to tutoring struggling students in classes at night or on the weekends. This work is mandatory for teachers, although they are paid for it. Chinese teachers usually teach at least two different classes each day, with 50-60 students in one class. In China, high school chemistry teachers seldom teach other subjects, even within the realm of science, but they need to substitute for their chemistry colleagues if their colleagues are sick or leave for other reasons.

Comparison of Teaching Methods and Learning Approaches

Chemistry teaching in China is lecture-based, teacher-centered, lab activity-supplemented, and strengthened by much practice. The whole teaching activity, from lesson planning, classroom activities, lab activities to assigning homework is quite different from the United States.

In China, lesson planning is done collectively as opposed to in the United States, where each teacher creates his or her lesson plans. Ordinarily, chemistry teachers of the same grade meet 2-3 times a week to plan lessons, prepare tests and synchronize the pace of their teaching. During this meeting, senior teachers work together with new teachers to make sure the new teachers learn from the senior teachers, so that all students obtain the same instruction (Su et al. 1994). The senior teachers are also assigned to observe the new teachers' classes and provide feedback and evaluations to them for further improvement. In contrast, American teachers' lesson planning is more individualized and independent. They can choose the content based on their own understanding of curriculum, and plan the lesson with much more freedom than Chinese teachers.

Lecturing, demonstrating experiments and explaining problem-solving steps are the primary chemistry teaching methods in Chinese schools, and the teacher is the center of the classroom. Chinese chemistry classes include new material sections and practice sections. In the new material class, the teacher teaches the lesson based on the textbook, and demonstrates chemical experiments. A Chinese chemistry teacher demonstrates at least fifteen different chemical experiments per semester. In the practice class, the teacher teaches extra advanced content out of the textbook, and provides students with problem-solving steps and repeated drills of exercises. In China, teachers are the authority in the classroom, and the teaching process is very serious and tightly structured. Since elementary school, Chinese students have been taught that it is rude to interrupt teacher’s lecture by asking questions or to initiate discussion, and they are also not encouraged to doubt and question teachers (Wang, et al., 1996).

On the contrary, American classrooms are student-centered with loose structure and a lively atmosphere. Teacher and students have a lot of interactions in the class, and students can freely pose their questions, move about the classroom, and initiate discussion. American chemistry teachers prefer to combine lecturing with interesting activities. Taking the topic of “chemical bonding” as an example, the typical Chinese way to teach this topic entails two lectures about ionic bonding and covalence bonding with an experiment demonstration and one more practice class. American teachers, however, might use one class for a brief lecture about ionic bonding and a hands-on activity, such as using egg cartons and beans to model the transition of electrons. They would then use another class to do a PowerPoint introduction of covalence bonding and a ball and stick model activity. The third day could be a cumulative balloon activity with practice. American teachers also love to use a lot of humor, anecdotes or even games to attract students’ attention and improve students’ engagement in the class. So, it is just as Su et al (1994) described that “Science teaching is a serious business in China, but it can be light entertainment in American classrooms” (p. 260). This student-centered approach and loosely structured class, however, sometimes makes the teacher’s instruction wander off to irrelevant topics, thereby wasting instruction time. One study stated that in general science classes, American teachers cover less content than a Chinese teacher would convey to students in the same amount of time (Su et al 1994).

Though schools are different, what students do is very similar everywhere (Goodlad, 1984). In both Chinese and American chemistry classes, listening, taking notes, participating in lab activities, and doing exercises are students’ common learning approaches. Chinese teachers are good at detailed explanations of problem-solving steps, and Chinese students generally build their thinking following the track modeled by the teacher, and then apply the model to other problems. Thus, Chinese students are usually stronger in logical thinking and deductive reasoning, but weaker in creative thinking than their Western peers. In contrast to Chinese students, American students are stronger in inductive reasoning, which may be a result of the fact that American teachers usually encourage their students to do their own exploration before the teacher’s explanation.

Chinese students learn chemistry along a spiral curriculum from level to level, and they are also trained well in synthesizing all the knowledge to work out difficult questions and problems. Furthermore, Chinese students generally have a strong mathematics background, which makes them more capable in calculation and logical reasoning. As a result, Chinese students perform better in science than American students on international tests (Gao, 1998). However, Niu and Sternberg (2003) also found that American students have higher creative ability than Chinese students, and they think this is the result of their inductive learning approaches and valuing individualism among American students.

Comparison of Chemistry Lab Activities

Though American students do more hands-on activities in the chemistry class, we observed that they have much less experience doing chemistry experiments than their Chinese peers. In comparing American and Chinese chemistry textbooks and curriculum, we found that American high school chemistry curriculum puts emphasis on principles and theories rather than the characteristics of elements and compounds, so American chemistry teachers seldom guide students to do chemistry experiments to study the chemicals. There is more concern in American classes about the safety of such experiments. Safety is a critical issue that is strongly emphasized in American classrooms. American teachers have to be concerned with parental disapproval and the threat of lawsuits, in addition to concern for the welfare of the student. Jonsson (2003, January) stated in an international daily newspaper that many American chemistry teachers hold back on experiments because of pressure from school officials who fear lawsuits. More than that, American chemistry lab activities are ordinarily conducted in the classroom with only the supervision of the chemistry teacher–since the classroom will get crowded when students move around to do labs, it becomes even harder to ensure a safe classroom environment. In contrast, Chinese chemistry lab classes are ordinarily conducted in an often-spacious chemistry laboratory built specifically for this purpose. Furthermore, a school staff member serving as a lab specialist will assist the chemistry teacher with supervising students in the lab class. Besides that, the Chinese cultural tradition makes the parents seldom question teachers' choices or bring an accusation against the school, which makes the pressure to ensure safety much lighter on Chinese chemistry teachers than on their American counterparts.

American chemistry teachers usually use one class to teach students safety rules and lab procedures at the beginning of school year, and require a safety contract with students and their parents. Chinese chemistry teachers like to separate the safety rules and procedures into small items, and include them with the explanation of every specific experiment (Liu, 2001).

Chinese students have to do about 6-8 required experiments and 4-5 elective experiments per school year. So, Chinese students do about 30-40 chemistry experiments during their four years of chemistry learning. The chemistry experiments in Chinese chemistry class are very structured and carefully designed. For example, the 9th grade Chinese chemistry curriculum requires students to understand the major components of air. After learning the properties of oxygen, students will do a lab producing oxygen through heating potassium permanganate and collecting the oxygen gas by a drainage method. Then they will do several small experiments to test the properties of the oxygen gas they produced. These real chemistry experiments help Chinese students to understand chemistry deeply. Despite the quality of Chinese chemistry laboratory experiments, individual investigations are discouraged in both Chinese and American chemistry lab classes. Students have to follow each step of the experiment procedures on the worksheet, and they are not allowed to test their own hypothesis or design their own experiments.

Challenges for Chemistry Education Reform in both China and the United States

Zhang et al (2004) stated that inquiry-based chemistry teaching and learning consistent with a constructivist view of science have been recognized as an important theme of chemistry education reform in both China and the United states. In current chemistry classes in both countries, however, inquiry is still a slogan more than a practice. Existing school chemistry education in China and the United States is actually test-driven, and the actual goal for learning chemistry is to get a good score in the National College Entrance Examination or to pass the statewide standard test.

Research also shows that many factors shape inquiry teaching and learning, and teachers' beliefs about the nature of science have been identified as the sustainable and critical factor that affects practices (Zhang et al. 2003). Embedding the nature of science in the curriculum of teacher candidate training program and high school chemistry textbook is critical for Chinese science education reform. In the United States, though the nature of science has been part of the content of high school chemistry textbooks, and scientific inquiry has been an important component of the pre- and in-service teacher training program, inquiry-based teaching and learning is still largely missing from American chemistry class because of the pressure and emphasis on statewide standard tests.

The pressure of the current testing systems is the biggest barrier for science education reform in both China and the United States. How to use these tests to positively guide, rather than negatively limit, high school chemistry education will be the biggest challenge for both Chinese and American chemistry education. More than ten years ago Fort (1993) pointed out that if today's students cannot achieve scientific literacy, then society will be in danger in the upcoming post-industrial era.

Another important way to implement education reform is to exchange education ideas among nations and learn advanced education practices from other countries. Chinese and American chemistry education systems both have their unique strengths as well as their respective weaknesses. The strengths of American chemistry education compared to Chinese chemistry education include: 1) the chemistry textbooks have more connections between chemistry and life; 2) classrooms are student-centered, with hands-on activities used to generate students' interest; 3) the inductive teaching method helps students learn through their own exploration. However, American chemistry education also needs some improvement in the following aspects: 1) the chemistry textbooks should be easier for teachers and students to use in the classroom; 2) the chemistry curriculum should be expanded and more information about the properties of chemicals should be added; 3) chemistry teachers should do more chemical demonstrations and students should do more chemistry experiments in class; 4) students need more practice with mathematics and solving more problems that require critical thinking. The strengths of Chinese chemistry education compared to American chemistry education include: 1) chemistry textbooks are well-designed with systematic curriculum and consolidated content; 2) there are many chemistry demonstrations and lab activities in chemistry class; 3) students learn much more chemistry knowledge through a continuous, spiral ladder. However, Chinese chemistry education also needs some improvement in the following aspects: 1) the nature of science and more connections between chemistry and life should be introduced into chemistry curriculum and textbooks; 2) teacher-centered classrooms should be replaced by student-centered classrooms, including encouraging students to question and discuss in the class; 3) the amount of busywork should be reduced, and more scientific exploration for students developed; 4) chemistry teachers should apply more technology in their classes and diversify their teaching strategies.

We hope this comparative study can provide Chinese and American chemistry educators some opportunities to learn from the strengths of another education system and offset their respective weaknesses, while maintaining their unique education characteristics.

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Why is the teaching of the Nature of Science Important?

Erin E. Peters

Explicit instruction about the nature of science can enrich science classes at all levels. Embedding such instruction in activities ranging from lab experiments to free-flowing class discussions can support student critical thinking skills, as well as provide them with a framework for deeper understanding of the lesson at hand.

Introduction

One of the most recent additions to Virginia State Standards of Learning in science, which appears from grade five through eight earth science, biology, chemistry and physics, is the nature of science. This standard for grades five through eight states, “The student will plan and conduct investigations in which an understanding of the nature of science is developed and reinforced” and the standard as stated in the earth science, biology, chemistry and physics standards reads, “a scientific viewpoint is constructed and defended (the nature of science)” (Virginia Department of Education, 2005). Additionally, the details of nature of science are explained briefly in a paragraph prefacing the standards as follows:

> The [subject] standards continue to focus on student growth in understanding the nature of science. This scientific view defines the idea that explanations of nature are developed and tested using observation, experimentation, models, evidence, and systematic processes. The nature of science includes the concepts that scientific explanations are based on logical thinking; are subject to rules of evidence; are consistent with observational, inferential, and experimental evidence; are open to rational critique; and are subject to refinement and change with the addition of new scientific evidence. The nature of science includes the concept that science can provide explanations about nature, can predict potential consequences of actions, but cannot be used to answer all questions (Virginia Department of Education, 2005).

What is “the nature of science” and why is it important to teach? The nature of science refers to the idea that scientists have inherent, agreed-upon processes and assumptions (Lederman, 1992) that help them to construct meaningful knowledge. It has taken educational researchers some time to pinpoint the important features of the nature of science (McComas et al., 1998). As more research is conducted, experts in the field have agreed upon seven different “aspects” of the nature of science: a) scientific knowledge is durable, yet tentative, b) empirical evidence is used to support ideas in science, c) social and historical factors play a role in the construction of scientific knowledge, d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, f) science is a creative endeavor, and g) science and technology are not the same, but they impact each other (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; McComas, 2004). This article discusses each of these aspects in detail and argues for the importance of understanding the nature of science in creating a more thoughtful science classroom environment.

The Aspects of the Nature of Science

Scientific Knowledge is Durable, Yet Tentative

The body of knowledge that forms the content of science is not fleeting, yet it is subject to change through a process of rational critique. New evidence can generate more studies in order to refine and change scientific knowledge. Laws and theories about phenomena such as the law of conservation of mass or atomic theory have been around for a long time. However, the body of knowledge we refer to as scientific knowledge is constantly being verified and refined with new data and technologies. Textbooks offer a stable source of science content knowledge, but they also present the material as if the information is in its final form (Duschl, 1990). If students believe that the knowledge in the textbook will forever stay the same, they tend to lose “faith” in science when they hear of a change in a scientific idea.

Empirical Evidence is Used to Support Ideas in Science

The Merriam-Webster *Dictionary* defines empirical as, “originating in or based on observation or experience” (Merriam-Webster *Dictionary*, 2006). Scientists who generate knowledge strive to be free from bias and attend to the subjective nature of human observation by addressing possible validity issues. Ideas are considered scientific if they can be verified (or refuted) by other scientists, are not based on opinion or belief, and are consistent with observational, inferential, or experimental evidence. When students express ideas about phenomena in the science classroom, they should be expected to explain the evidence that supports their ideas.

Social and Historical Factors Play a Role in the Construction of Scientific Knowledge

One of the most famous cases of social and historical factors playing a role in the construction of scientific knowledge is the story of Alfred Wegener’s ideas about continental drift. Wegener proposed his idea about continental drift in 1912 (United States Geological Survey, 2006). He stated that all of the continents on the earth were broken pieces of one large land mass called Pangaea. The mass of land broke in several stages, resulting in our current configuration of continents. He based this idea on the evidence in fossil records from which he observed the same species along coasts of different continents, as well as the puzzle-like fit of the shapes of the continents. His idea was not well received because the prominent idea at that time was that the continents were immovable. Wegener offered no mechanism that could move something as massive as a continent. Additionally, social factors contributed to the reluctance to accept Wegener’s idea. Wegener was an outsider to the community of geologists as he was a meteorologist. Geologists at the time were reluctant to reform their paradigm for an idea from an outsider (Kuhn, 1996). Wegener spent the rest of his life trying to support his idea until he froze to death in 1930, attempting to gather evidence. Shortly after

Wegener's death, information about ocean floor spreading was discovered which provided a mechanism for continent movement. Once the mechanism for movement was discovered, the theory of continental drift was considered valid scientific knowledge, and is widely known and accepted today.

The Difference between Laws and Theories

A misconception in science is that there is a logical progression from hypothesis to theory to law. Diagrams in many textbooks often inadvertently encourage this misconception. Laws are a different kind of knowledge than theories. Laws are the rules that guide the movements and properties of phenomena. Laws answer "what happens when . . . " type questions. For example, the law of conservation of mass states that when matter in a system changes either by physical or chemical means, no mass is lost or gained in the system. However, the law does not attempt to explain *why* no mass is lost or gained. Theories constitute the "why" type of knowledge. In asking why no mass is lost or gained, one must turn to information provided by particle theory. If science students only understand laws they can predict the outcomes of phenomena well, but do they know science? Having a balanced curriculum of theories (the "why" questions) and laws (the "what happens when" questions) guides students toward deep scientific thinking.

Accurate Record-keeping and Peer Review

The habits of mind of science may be the most easily accessible to students of all of the aspects of the nature of science. Since scientific claims must be based on evidence, the records that document experiments must be understandable to other scientists. There are many methods for choosing research problems, gathering data, analyzing data and reaching conclusions. Furthermore, the methods used in solving a problem scientifically do not follow a prescribed order. Scientists must provide a rationale for the options they choose so that other scientists can follow in a logical way. For an idea in science to become valid, others in the field must be able to read and interpret the data presented to determine if the conclusions fit the trends in the data. Similarly, students must provide rationales for their choices in solving problems. One way to encourage this scientific habit of mind is to ask students who are recording data if they would be able to understand their information weeks or months from now. Another technique to encourage accurate record-keeping is to have students rigorously review other students' papers. Peer review has two goals: to simulate scientific practice and to provide feedback on the clarity and logical sequence of student work.

Science is a Creative Endeavor

Traditionally, scientists are perceived as people who perform experiment after experiment alone in their laboratory (Ryder, J., Leach, J. & Driver, R., 1999). Doing science actually requires quite a bit of collaboration and creativity. Choosing problems, collecting data and analyzing data require thinking on a creative level. Scientists need to make the leap from analysis to conclusions and that certainly requires creativity. The way science is presented publicly downplays the importance of creativity in the scientific process because the communication of scientific ideas is presented as having a rigidly structured format, creating an illusion of order: introduction, hypothesis, data collection, data analysis and conclusion. Most scientific studies do not play out in this prescribed format; rather, they entail a more human aspect involving spurts of ideas as well as unexpected outcomes. It takes creativity to look at something as mysterious as nature and extract an idea from the chaos.

The Relationship of Science and Technology

Science and technology certainly are related, but they are often misunderstood to be the same thing. Science is the body of ideas about how the world works. Technology provides the tools we use to look at or modify the way the world works. Science and technology have a leap-frog-like relationship. Science provides ideas about how a particular phenomenon works which, in turn, produces tools related to the phenomenon. The tools are used to look closer at the phenomenon and lead to refined scientific ideas, which lead to better tools, and so on.

When a scientist thinks of questions and seeks answers, the knowledge he or she acquires is guided by these seven aspects of the nature of science, among other influences. As science teachers, we try to provide experiences for students that resemble as closely as possible the experiences of scientists. This requires knowledge of how science operates as a discipline. Teachers can use the aspects of the nature of science to assess the information and processes taught in their classes in order to encourage scientific thinking.

Creating More Thoughtful Classroom Experiences

Students who know factual knowledge about science can pass a high-stakes test, but can they think scientifically? It is certainly possible to cover the curriculum by drilling science facts, but teaching in this manner creates the idea that science is a series of disconnected topics. When ideas about *how* scientific knowledge is constructed are presented along with scientific facts and ideas, the result is a more comprehensive understanding of science. That is, teaching how science information was found and verified helps students build strong, related ideas about scientific knowledge and discourages misconceptions. Many teachers have seen students be successful in completing cookbook-type labs without being able to communicate an understanding of the concept of the lab. In such cases, the students dutifully followed the steps provided, demonstrated science process skills, but did not engage with the material or the activity. By teaching and emphasizing the nature of science, teachers can provide the underpinnings for successful understanding of concepts in laboratory investigations—an understanding of the nature of science promotes an understanding of the rationale behind the process skills. When students are aware that performing multiple trials of an experiment, for example, provides valid empirical evidence toward a claim, they are more likely to be attentive to the meaning of the trends in the trials.

Explicitly Teaching the Nature of Science

Research has shown that teachers who assume students will implicitly learn the nature of science through inquiry activities do not, in fact, develop student understanding of the nature of science (Bell, Blair, Crawford, & Lederman, 2003). Student understanding of the nature of science is more effective when the nature of science is taught explicitly (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick and Akerson 2006). This does not mean that each student should have to memorize and regurgitate the seven aspects of the nature of science. Teaching the nature of science explicitly requires a teacher to find "teachable moments" where the rationale for performing a scientific habit of mind or describing the ideas that have led to current scientific ideas can be illustrated.

Enhancing Inquiry

Another reason to teach the nature of science is due to its ability to enhance the quality of inquiry experiences (Peters, 2006). High quality scientific inquiry investigations follow processes and assumptions made by scientists about how to do science (Lederman, 1992). Teaching the nature of science provides a worthwhile extension of inquiry, because students are exposed to more than scientific content and process. Contact with the aspects of the nature of science during inquiry can put investigations into historical perspective for students, or demonstrate the role of the development of technology to improve the accuracy of measurement. Augmenting inquiry with the nature of science can provide alternate ways of knowing that scaffold student understanding. When students learn about the nature of science in conjunction with inquiry, their understanding of and knowledge about how and why scientific content and processes came into being is boosted.

The Nature of Science and Current Events

An understanding of the nature of science can also help to provide a problem-solving framework for difficult controversies such as creationism and global warming. Students are sometimes confused about the role of "creation science" in the science classroom. A closer look at "creation science" reveals that it is based on beliefs instead of empirical evidence which shifts the topic of "creation science" into a non-science realm. Students are also sometimes confused when they find reputable articles that present both sides to the arguments regarding global warming. When students use the aspects of the nature of science as a filter for information, they can judge the validity of information so that they can form their own logical arguments.

Fitting the Nature of Science into the Science Classroom

The current science curriculum is jam-packed with content, so how can teachers possibly add another topic, the nature of science, to this already long list of topics? Teaching the nature of science should not be done separately from science content. One way to effectively teach the nature of science is to incorporate it into existing content by explaining how the current content became valid scientific information. When teaching about atoms, a teacher could explain how the idea progressed from ancient Greece to current times, emphasizing the tentative nature of science (as is outlined in Robin Curtis' article "Development of Atomic Theory" in this issue). Students who make claims about phenomena should be able to back up their ideas with empirical evidence. Questions can be embedded into existing lessons that ask about the implications historical events had on science and technology such as the effect of the French Revolution on the development of the metric system. Instruction can point out to students when laws are being used to construct knowledge and when theories are being used to construct knowledge. Students can review each others' data for clarity. The differences between science and technology can be emphasized by asking students to fill out a T-chart separating science and technology in laboratory experiences.

It is important for students to understand the way science knowledge is developed and validated because it moves students away from being vessels filled with scientific facts toward becoming critical thinkers. An understanding of the nature of science can promote more authentic inquiry investigations and can help students identify rigorous scientific arguments in confounding situations. Teaching the nature of science should add a deeper dimension to science curriculum by providing a reason behind the development of scientific ideas.

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Create a Timeline of Science History in your Classroom

Christine G. Schnittka

The University of Virginia's science education lab hosts a colorful timeline mural of the history of science. Painted and designed by graduate student Christine Schnittka, this mural begins with the 1531 sighting of a comet and ends with its 2061 predicted return. The mural contains many familiar scenes with reoccurring themes, reflecting the changing face of science. Students at the University are learning a little more science history each time they come to class. Justification for and process of creating the mural, and a link to a website with images of the entire project are included.

Continuity and Connections

There is a wall in my house full of family photos: great-grandma and grandpa, aunts and uncles, cousins and new babies remind our family of where we have come from and where we are going. It is a "snapshot" image of who we are as a family and a daily reminder of how each of us fits into a much larger community. This practice is replicated in many homes, and it gives each visitor a warm feeling of continuity and connections.

The community of scientists, past and present, is like a family tree. Connected and continuous, scientists "stand on each others' shoulders" in much the way a family tree is made of roots, branches, twigs and leaves. When a young person enters a science classroom to learn a particular concept or skill on a particular day, that concept or skill is linked to a history of people who spent their lives devoted to the advancement of our understanding of the universe. A visitor to a busy science classroom can feel that sense of continuity and connection too, especially if the classroom has something like a family photo wall of scientists.

At the University of Virginia, I painted such a wall in the summer of 2005, in the classroom used by each and every UVa student of science education—the classroom where future science teachers are brought up. It was not actually one wall, but four: all four walls are painted with a timeline detailing the history of science. It is a timeline of faces and images, a timeline that places those who work in that classroom into a larger community of scientists and their discoveries.

The Timeline of Science

The timeline begins in 1531 with the vision of a comet, observations of which have been recorded throughout history, notably by Chinese, Japanese, Babylonian and Islamic astronomers. This comet, later to be named after Edmund Halley—who saw it when it appeared again in 1862 and predicted its regular return—makes it appearance predictably on all four walls of the classroom (Figures 1-4).

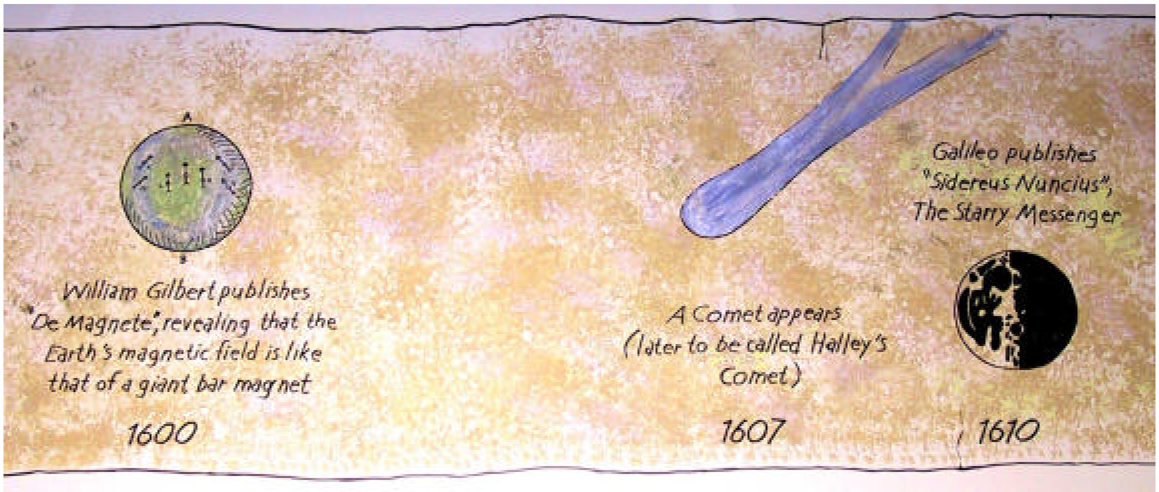

Figure 1. A comet returns in 1607 as secrets of the Earth and Moon are revealed.

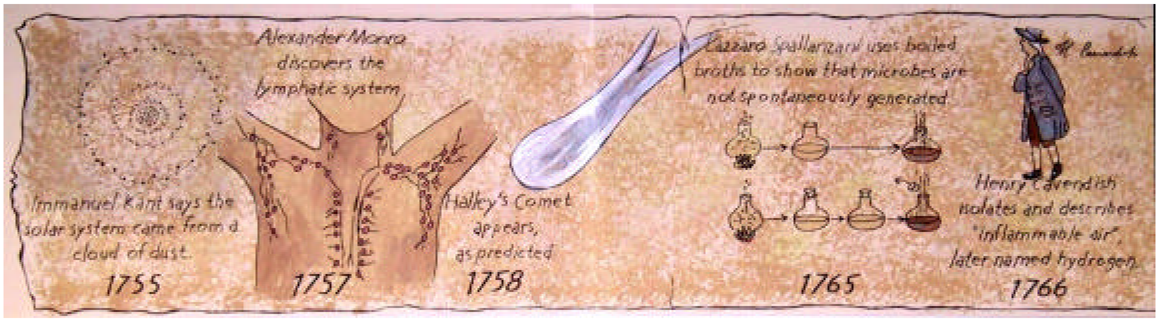

Figure 2. Microbes and lymph nodes flank the appearance of Halley's Comet in 1758.

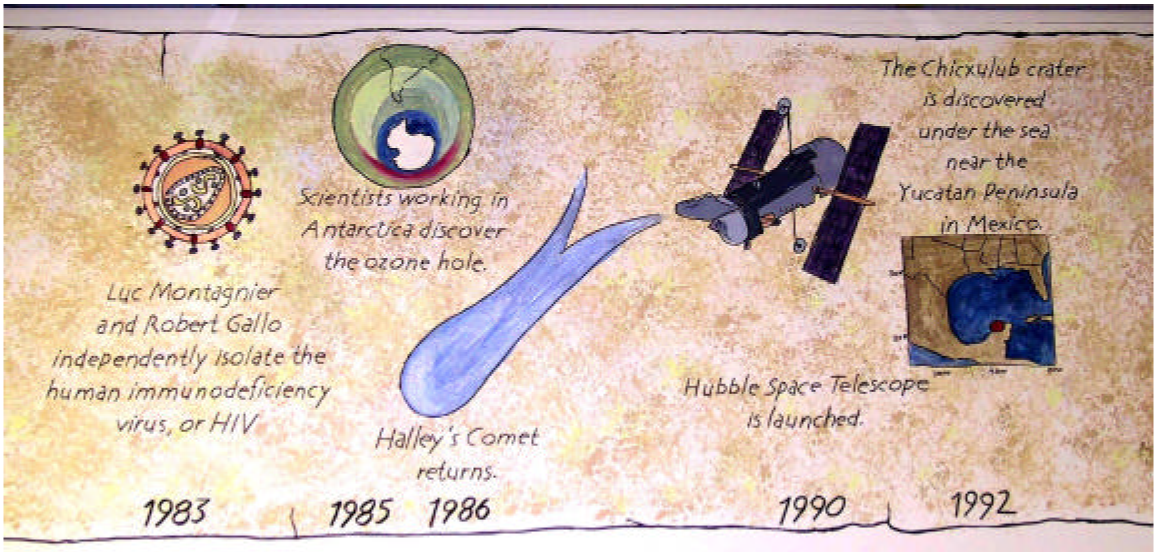

Figure 3. Halley's Comet returns in our lifetime as a deadly virus and the vast expanses of space are revealed.

Figure 4. The future return of the Comet.

In the first corner of the third wall, Louis Pasteur is flanked by the images of Alfred Wallace and Charles Darwin and the map of Dr. John Snow's cholera-infested London (Figure 5) as the structure for benzene and helium's discovery on the Sun lie ahead.

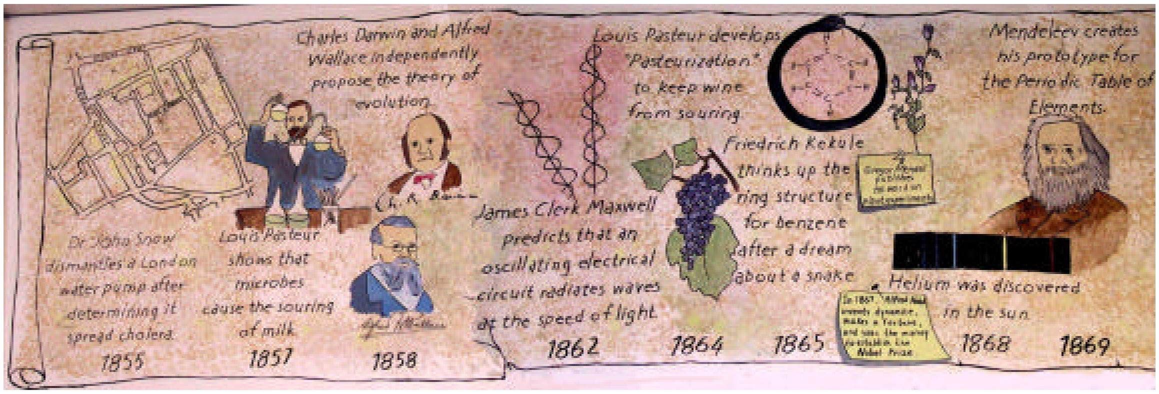

Figure 5. Snow, Pasteur, Darwin and Wallace are in one corner.

Further along this wall, past and future are revealed in the discovery of a coelacanth, in the development of carbon-14 dating, and in Barbara McClintock's discovery of telomeres. George Gamow's prediction sets the stage for future debates and discoveries about our universal inception (Figure 6).

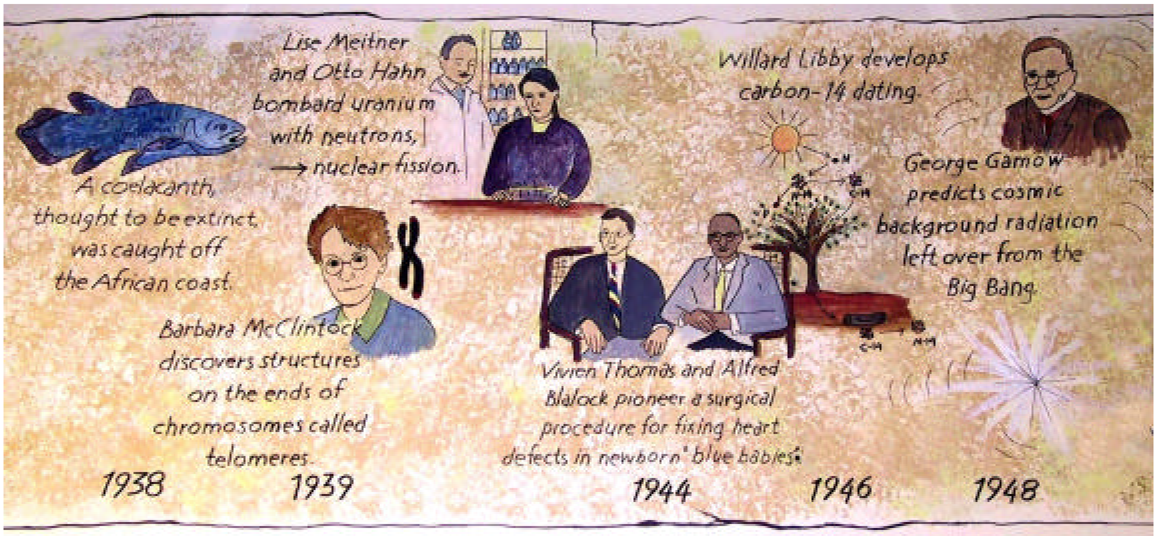

Figure 6. Ancient past and hints of the future co-exist.

The sights and scenes on the timeline change as the years go by. Each new discovery opens doors to future lines of research. Ideas are revised as new technologies allow for better means of observation. The modern faces reflect a more diverse population of scientists, and the latest decade reflects the frenetic pace of advancement in scientific discoveries (Figure 7).

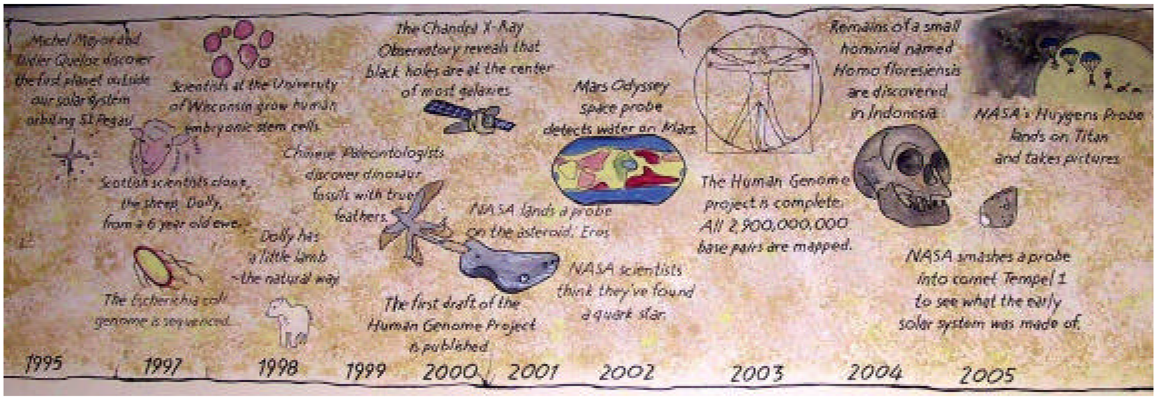

Figure 7. A frenetic pace of scientific advancements has occurred in the last decade.

A Case for History

Efforts have been made to include the teaching of the history of science in the science curriculum for many years, with some promising results. Some studies show that understanding the history of science helps students and teachers achieve conceptual change (Feigenberg, Lavrik, & Shunyakov, 2002; Seroglou, Koumaras, & Tselfes, 1998; Wandersee, 1985), encourages positives attitudes towards science (Seker & Welsh, 2006; Solbes & Traver, 2003; Welch & Walberg, 1972), advances understanding of the nature of science (Carrier, 1962; Galili & Hazan, 2001; Lavach, 1969; Lin & Chen, 2002), and aids in more conceptual learning (Galili & Hazan, 2000; Jensen & Finley, 1995).

Now, national reform documents are including the history of science as a valuable asset to science education. The Benchmarks for Science Literacy (AAAS, 1993) state that "there are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples….A second reason is that some episodes in the history of the scientific endeavor are of surpassing significance to our cultural heritage." Having a timeline of science in the classroom with images of people from cultures around the world, and significant episodes of scientific discoveries provides such concrete examples.

The National Science Education Standards (NRC, 1996) state that "in learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise." Creating a visible timeline of the history of science is one step toward reaching that goal. Its daily presence serves as a constant reminder of where we are today, how we have come so far, and how tentative science actually is.

However, the research shows that teachers are not bringing the history of science into their classrooms (Wang & Cox-Petersen, 2002; Wang & Marsh, 2002). While they value the teaching of the history, they feel they don't have the time to devote to the effort. I will be the first to admit that painting a 50 meter-long mural is a time-consuming effort (it took approximately 150 hours)! However, if students are involved in the task, and if the groundwork I have established is used as a springboard, the task may not be as daunting as it seems.

Helpful Hints

The Internet provides a wealth of information and images from which to create a timeline specific to either a time period or a science discipline. One trick I used for transferring images of people and primary source documents was with tracing paper and carbon paper. After finding just the right image, I placed tracing paper directly over the computer screen and traced the details. When it came time to transfer the image to the wall of the room, I put a piece of carbon paper between the wall and my drawing, and traced over the lines again. Acrylic paints and water-based poster-paint pens completed the task. Actually, the research was the hardest part.

With thousands of years of science history, which events should you choose to grace your classroom walls? While I went for the familiar, the fascinating, and the personal faces of science, you could focus on a theme, or otherwise limit the breadth of the family tree-of-science. No matter what you create, your students and the visitors to your classroom will come away with a sense of continuity and connections, a snapshot of where we are in the history of all things science, and a better appreciation of the shoulders upon which we stand so that we may see further.

More Information

For more information about this project, including an immense list of historical moments from which I gleaned my final selections, and brief stories about the moments that made it onto the wall, visit my website at www.people.virginia.edu/~cgs2d/mural.htm

Special thanks go out to University of Virginia's science education professor Randy Bell who allowed me to paint his classroom, and to department chair Daniel Hallahan and Dean of the Curry School David Breneman for supporting this opportunity.

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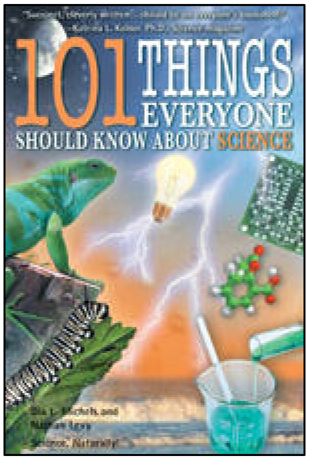
Review of current publications affecting the teaching of science

101 Things Everyone Should Know About Science, by Dia L. Michels and Nathan Levy. Science, Naturally, 2006. $9.95. (www.ScienceNaturally.com)



The first thing you wonder as you flip through this attractive little book is, What for? What would I do with this lightly illustrated 160-page collection of questions and answers about everything from flying mammals to double-blind placebo-controlled studies? Who would read it? Why? When? Where?

Spend a little more time flipping through the book and the answer begins to dawn. This'd be the perfect book to leave lying around in your upper-elementary, middle-school or high-school classroom. You'd make it available—maybe a couple of copies, even—so when the kids finish their lab or quiz or reading or whatever they might pick it up and browse.

You can imagine the questions—there are 20-some each for biology, physics, chemistry, earth science and general science. So in biology you'll find, "At room temperature, some elements are gas, some are liquid, but most are ___________," and "What happens over time when iron is exposed to oxygen?"; in physics, "Name a machine that operates without any external power source," and "Why is walking on ice or driving on wet roads so difficult?"

The answers, of course, are the best part. So in earth science we find "Is a lunar year shorter or longer than a solar year?" We turn to page 101. For starters, there's simply, "Shorter." But then there's nearly a page of explanatory information: 365.26 days for the solar year, almost 1.5 more days for the lunar year because...well, you remember, don't you? The answer goes on to explain the difference between the Christian solar calendar and the Muslim and Buddhist lunar ones, addressing some of the social and religious ramifications of each.

In biology you can learn (be reminded of?) how many legs an insect has—six—but you can also learn something about prehistoric insects, the top speed of a butterfly (19.6 kph), and the weight of the world's heaviest beetle (71 g.—it's an endangered species, living in New Zealand). In chemistry you can learn that water boils faster at low than at high altitudes because of the impact atmospheric pressure has on vapor pressure—as well as being reminded that you should "check food labeling to see if there are special instructions for higher altitude cooking."

101 Ways is a book for those kids who just can't get enough science—or maybe for those kids who didn't know how much science they wanted to get. That means, of course, that it won't be a book for everybody. But there are lots kids out there it'll work for—and for them, it'll really work.

This is indeed a pleasant book to have around, maybe to give as a present or a prize for those students who make it worth your while to show up every day.

Nick Boke

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Anyone interested in reviewing submissions should email nboke@cox.net, specifying areas of interest and expertise.