NETWORK OF EDUCATORS IN SCIENCE & TECHNOLOGY

Working to Promote Science Literacy in association with the Massachusetts Institute of Technology

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Contents

Co-Chair Report
Failure *is* an Option!

Steve Cremer [NEST '91]

Over the past few years, I have been exploring the role of failure in learning and education. It has become my concern that too much of our education system is focused on having students learn the right answers and not on developing their understanding and their ability to use their experiences to solve new problems.

Dr. Woody Flowers, Professor Emeritus, MIT, has been similarly concerned and has identified what he feels is part of the problem.

> "I believe that education and training are different. To me, training is an essential commodity that will certainly be outsourced to digital systems and be dramatically improved in the process. Education is much more subtle and complex and is likely to be accomplished through mentorship or apprentice-like interactions between a learner and an expert. To clarify a bit: Learning a CAD program is training, while learning to design requires education; learning calculus is training, while learning to think using calculus requires education. In many cases, learning the parts is training while understanding and being creative about the whole requires education."

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MIT SEPT: Inspiring Educators From Around the World

Rachael Manzer [NEST '13]

Over the course of our careers as teachers, we have all attended numerous professional development sessions. Have you ever come back from a workshop where you were so energized and inspired that you could not stop talking about it, even months after the workshop has occurred? That is the experience I had in June 2013 after participating in the MIT Science and Engineering Program for Teachers (SEPT).

I was one of 30 teachers from around the world that participated in the one week SEPT at MIT. After the first day, I clearly understood MIT's famous expression of "drinking from the fire hose." Every day, teachers from MIT taught us about the latest and greatest research in science, technology, engineering and mathematics (STEM). This was not done by listening to lecture after lecture, but rather through hands-on activities and simulations that we could bring back and implement in our classrooms. For example, the teachers modeled DNA using LEGOS, experienced sustainability within an ecosystem through a computer simulation called Fishbanks, toured laboratories at Koch Institute to learn about the use of nanotechnology in cancer, used web based microscopes to become citizen scientists, and

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Climate Change Impact

[This editorial by Marcia McNutt appeared in *Science* on August 2, 2013.]

Anticipating the future under the influence of climate change is one of the most important challenges of our time.…The natural systems that provide oxygen, clean water, food, storm and erosion protection, natural products, and the potential for future resources, such as new genetic stocks for cultivation, must

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Calendar of Events

November
Renew membership (instructions will be sent by email)

January
NEST Executive Meeting (date to be determined)

January 31
Deadline for:

- NEST Teacher of the Year Award nominations
- McNamara Workshop proposal applications
- NEST Student Award requests
- NEST Reunion registration

February 28
Deadline for submitting name for consideration as a SEPT host

March 1
Submission deadline for the spring newsletter

March 1
Deadline for Co-chair and representative nominations by email

March 14
Deadline for SEPT 2014 applications

March 31
Deadline for:

- NEST Teacher of the Year Award nominations
- McNamara Workshop proposal applications
- NEST Student Award requests
- NEST Reunion registration

April 1
Deadline for Co-chair and representative votes by email

April 9
Deadline for registering for the NEST reunion

April 25
Announcement of recipients of:

- NEST Teacher of the Year Award
- McNamara Workshop presenters

May 2
Student Award books and certificates are sent out to nominating teachers

June
2014 SEPT conference & NEST Reunion (dates to be determined)

Editorial

NEST is headed in a new direction. Under the leadership of Ron Latanision, we are looking at what we can do to influence the actions taken by our government that influence STEM education.

Last July, about 20 NEST members went to George Washington University for a four-day Policy Institute. We got input from educators in DC and a lobbyist to understand what is going on regarding education reform and we attended workshops led by members of the National Academy of Sciences (NAS), the American Association for the Advancement of Science (AAAS) and the American Chemical Society (ACS).

In addition, we attended a session of the President's Council Advisors on Science and Technology (PCAST) and spent a morning visiting our senators and congressmen and presenting our perspective of what should be their concerns, giving the often absent input of experienced educators. We are the ones who have to deal with the policies they set, so giving direct feedback and input is critical. Not only do we have to educate our students—we also have to educate our legislators!

This will hopefully be the beginning of a new direction for NEST. It has the potential to have a meaningful impact that can influence the future of our profession.

Greener Plastics

[These excerpts are from a brief article by Paul Anastas that appeared in the July/August 2013 issue of *Technology Review*.]

The most well-documented concerns about traditional plastics relate to their persistence in the environment. Plastic bags and water bottles fill up landfills, and plastic fragments gather in gather in high concentrations in a large area of ocean known as the Great Pacific Garbage Patch. Less well known is that for every bit of solid waste floating in the ocean, as much as an equal amount of soluble plastic has dissolved in the water, where it can harm marine life.

Avoiding these problems doesn't mean we have to do without plastics. It is possible to create plastics that end their lives without polluting or poisoning….

Plastics created using the principles of "green chemistry" are designed to reduce or eliminate the use and generation of hazardous substances throughout their life cycle. This means nontoxic, renewable feedstocks, a manufacturing process that yields little or no waste, and a final plastic that, when discarded, degrades into harmless products on a human rather than a geological time scale.

Green plastics can be made synthetically, but most are made from biomass feedstock….

Growth in the use of biofuels, though modest, increases the incentive to develop applications for nonfuel materials used in biorefineries. Progress is being made toward addressing the performance limitations of bioplastics….

Most important, research is showing that formerly recalcitrant feedstocks such as grasses, agricultural wastes, and wood are promising bases for new materials. These plastics may have not only an environmentally friendly life cycle but enhanced performance, functions, and capabilities.

Joe Scheller [MIT '54] has been an active supporter of NEST for many years. He is now seeking input on ways to train and advise retirees, such as himself, to be able to mentor or assist students in science classes. What do they need to know? What training is needed? When could such assistance fit into the school time schedule? Should the student/mentor relation be confidential?

He envisions it as being a combination of academic assistance and helping set the perspective of the future. This will hopefully help motivate students toward applying themselves in school. Please contact Joe at ritaandjoe@verizon.net.

Any Physics teachers out there looking to analyze and graph the motion of a falling body? Any Environmental Science teachers looking to get data on changes in vegetation? Any Astronomers looking to analyze the colors in an image of a star? Need to calculate the area of a region? Want to measure the distance between two points in an image? There is software available to do all that and much more! Analyzing Digital Images (ADI) was written by John Pickle, an instructor at Concord Academy, when he was associated with the Boston Museum of Science. Better yet, it is free!

UMass Amherst ran a summer program for teachers, STEM Digital. One of the instructors was the originator of this software who taught us how to analyze images and even how to video and graph and calculate the motion of a falling body. Not having a degree in physics, I will freely admit some of it went over my head, but the software, its manual and lesson suggestions are supported by the Lawrence Hall of Science at the University of CA, Berkeley. The latest 2013 version is available for download at: www.globalsystemsscience.org/software/download.

The older version, which was used at UMass, is available at: www.umassk12.net/adi. I use the older version since that is what I was trained on and on which I based my lessons. There is very little difference between the two versions, but the newer version is a bit more user friendly. One of my goals for this coming school year is to rewrite my lessons for the new version.

Even if you don't teach physics, astronomy or environmental sciences, check out this software to see what you can do with it to help teach your curriculum. If you have questions, contact me, **Sharon Cumiskey [SEPT '10]**, at skey1952@comcast.net.

Dana Dunnan [NEST '89] has just published a book for new high school teachers. There were many things he didn't get in teacher training which would have been helpful, so he has tried to fill that gap. The book has 60 pages for beginning chemistry teachers and 20 pages about his experiences in teaching journalism. The other 140 pages are aimed at high school teachers in general, and the entire book has aspects of a memoir. For those of you who he has known in NEST, the conversational and sometimes humorous tone of the writing should sound familiar.

To make it affordable to beginning teachers bearing the crushing load of college debt, the paperback is $7.99 plus shipping and handling, and the Kindle is $1.99, plus any charges the government attaches for monitoring your phone calls and emails. Dana feels that his book is not going to make any money, but, hopefully, it can make better teachers.

The website www.chalkdustmemories.com has extensive details on the book, including a lot of samples from various chapters. If you go to the website, or better yet, read the book, and are impressed, please let someone know who might benefit. If you go to the website or read the book and hate it, you would find a monastic vow of silence spiritually uplifting. If you have any questions, you can contact Dana at dunnandj@gmail.com.

The Internet System for Networked Sensor Experimentation (iSENSE) was developed by UMass Lowell and Machine Science, Inc. The iSENSE system (http://beta.isenseproject.org) is free and it allows students to immediately share and view data they have collected. Thus, it serves to promote collaborative scientific inquiry. Currently, there are three Android Apps for physics applications. These include: recording and visualizing GPS/map-based position data, linear acceleration data and pendulum periodicity data. The students set up the experiments, having the Android tablet (with sensor Apps) collecting the data. The tablet interfaces with iSENSE sending the data via Wi-Fi or mobile service.

The data can be graphed on a Google map, annotated time line, scatter chart, bar chart, histogram or motion chart. The visualization tools allow a student to select small subsets of experimental data to analyze as well as the capability to analyze the complete dataset. The scatter chart allows students to choose which attribute they wish for the X and Y axes. Students can visualize the data in many ways, quickly allowing them to find correlations, observe trends and determine outliers to a dataset.

In addition to the Android Apps (sensor data), the program can be used as a visualization tool for student data collected from any science experiment. This is done by creating an experiment link. Afterwards, data can be keyed in manually or a data file uploaded. Each student then has immediate access to the complete classroom data set which can be analyzed with the powerful visualization tools.

If you have additional questions, contact **Helen J. Flavin [NEST '10]**, Ph.D., at hflavin@bishopconnolly.com.

A flight of fantasy, whether in dream or daydream, is no mere slight of mind. But only children will accept it as being equally as profound as the arbitrary state of awareness we are taught to regard as reality, and hence, only they are nurtured by it....A true belief in the validity of nonordinary reality—with all that it can teach us—seems beyond the capabilities of every practicing adult....

— Garry B. Trudeau, *The Doonesbury Chronicles*

Commentary on Common Core

[This commentary on conservative concern by Cory Turner was on National Public Radio on June 24, 2013.]

"Common Core" is one of the biggest phrases in education today. To many educators and policymakers, it's a big, exciting idea that will ensure that America's students have the tools to succeed after graduation.

But a growing number of conservatives see things differently.

For years, states used their own, state-specific standards to lay out what K-12 students should be learning, for everything from punctuation to algebra. But those standards varied wildly, so the Common Core replaces them with one set of national standards for math and English language arts.

Forty-six states and the District of Columbia have signed on to the Common Core. But with those states now beginning to implement them, the core standards have become a rallying cry for some conservatives. Opponents have levied several arguments against the common standards.

Argument 1: "Washington Should Stay Out Of The Classroom"

"This is an effort largely driven by national organizations and the federal government," says Lindsey Burke, an education fellow at the Heritage Foundation, a conservative think tank. "And for many, the fear is that that will come at the expense of state and local control of education."

Burke is quick to point out, however, that the federal government is actually prohibited by law from telling states what or how to teach.

But Michael Cohen, president of Achieve, a nonprofit that helped create the Common Core standards, says Common Core didn't come from Washington.

"The idea of creating the standards and the work of creating them was led by governors of both parties," he says. "And there was not a federal dollar involved in their development."

While the Common Core standards were created by those state leaders in 2009, federal dollars do come into the story. President Obama used them, through No Child Left Behind and his own program, Race to the Top, to entice states to adopt the core. And some conservatives say that effort crosses a line.

Argument 2: "Don't Tell Us How to Teach Our Kids"

As backers see it, these national standards tell states what kids should know by which age—but not how to teach them. But to opponents, there's little difference between standards and curriculum.

"You actually see textbooks now [that] bright and splashy on the cover say, 'Common Core-aligned textbooks,' " says Burke.

The new standards even come with a list of recommended reading, including Macbeth and The Grapes of Wrath. The concern for many is that a teacher who has assigned books not included on that list will now stick to the recommended titles instead. Then, opponents say, every kid in the country will end up reading the same books and the same ideas.

Argument 3: "This Will Cost Money"

Everyone on both sides of the standards agrees that implementation of Common Core will cost money. There are tests and new textbooks, and teachers will need to be retrained. But Achieve's Cohen says the Common Core is money well-spent if it means kids are taught to read and think critically—something he says schools have not been doing.

"We can continue to not do that," he says. But saving money on things like new instructional materials, he says, will also mean "[continuing] to have students who need to take remedial courses when they get to college, and [about] whom employers say, 'They're not well-prepared for the jobs that I've got.' "

Michigan State Rep. Tom McMillin, a Republican opposed to the standards, has decided the Common Core's price tag could help him stop school systems from using it. Schools may decide they want to adopt the core, he says, "but if they don't have the money to implement it, then they're not going to be able to do it."

That's because in Michigan, as in most states, adoption of the core was up to the State Board of Education. But funding has to go through McMillin and the state Legislature, so McMillin added an amendment to the budget that as he describes it, says, "Not a dime of the money that's given to the Michigan Department of Education can be spent on implementing Common Core unless there's an affirmative vote of the Legislature to do so." Conservative lawmakers in other states are using similar tactics.

So while districts across the country move ahead with implementation, one big question still looms over it all: Just how common will the Common Core be? [Copyright 2013 NPR]

Science Left Behind

[These excerpts are from a review of *Science Left Behind* (by Hank Campbell and Alex Berezow) that was written by Enrico Uva that appeared in the February 2013 issue of *Chem 13 News*.]

Campbell and Berezow argue that regardless of which political party is in power, science takes a back seat. Since 1987, Republicans and Democrats have each been elected for three terms and federal research and development's share of GDP has declined or stagnated while non-federal investment keeps increasing. Science is disregarded in making decisions or is merely used to rationalize after a choice was made for other motives. One of the examples cited is the Obama administration's decision to use scattered radioactive waste disposal sites instead of opting for one geologically secure place like Yucca Mountain.

…The authors made it clear that we need laws to protect consumers against companies' ghostwriting in medical journals, data-tampering and clinical trials involving defenseless children in places like India. But they emphasize that a suspicion of all modern pharmaceutical products is not the answer. Similarly, the authors recognize that habitat loss and poaching are genuine concerns, but the approach of PETA and more radical groups on animal issues in general is not based on science.

They sympathize with academics who were forced to resign for making statements that were not scientifically flawed but offensive to what's referred to as the "progressive censor machine." Teachers may also relate to their fear that science will suffer if social engineering is given priority over excellence.…

Kudos

Stephen Anand [NEST '06] received the 2011 NACT "Teacher of the Year" Award and the 2012 Dwyer Award for Excellence in Education.

Jake Bogar [NEST '13] and **Tracy Vassiliev [NEST '13]** are sharing their SEPT MIT experience in a presentation session titled "Resources for Teachers from MIT Science and Engineering Program" at the Maine Science Teachers Association (MSTA) 2013 Conference on Friday October 11th at Gardner Area High School.

Bette Bridges [NEST '90] and **Betty Catelli [NEST '95]** were presenters this past summer at Chem Ed 2013 in Waterloo, Ontario.

April Lanotte [NEST '08] has been offered a master instructor position at the University of Colorado at Colorado Springs for their UCCSTeach program, that allows math and science majors the opportunity to get their math or science degree and their teaching credential at the same time, without extra time or money.

Rachel Manzer [NEST '13] was identified as the 2013 Region #1 (New England) Magnet School Teacher of the Year and also led a week-long "Teachers in Space" space flight experiment at the Aero-Institute/NASA Dryden Research Center.

An article by **Janice Mooney-Frank [NEST '11]** entitled "Elementary Gardeners Celebrate Earth Day" was published in the Summer 2013 issue of the Connecticut Journal of Science Education.

A letter-to-the-editor on the NEST effort in DC submitted by **Avi Ornstein [NEST '89]** was published in the August 10, 2013, issue of the *New Britain Herald* and one by **Mark Hungate [NEST '90]** was published in *The Berkshire Eagle*. Similarly, **Joyce Gleason [NEST '92]** wrote to alert her supervisors at FL Gulf Coast University.

Artwork by **Elly-May O'Toole [NEST '10]** was displayed at the Marion Art Center Photography Show in Marion, MA, that occurred from April 26th through June 1st.

Pamela Rickard [NEST '13] facilitated a CalPoly EPIC (Engineering Possibilities in College) summer camp for middle school students in July 2013, taught STEM projects for teachers at the CUE Rockstar teacher camp on the USS Hornet in San Francisco in July and August 2013 and will present at the October 2013 NSTA conference in Portland, OR.

Steve Rocketto [NEST '90] received the national Civil Air Patrol Frank G. Brewer Memorial Award for Aerospace Education.

Tracy Vassiliev [NEST '13] had students in the 2013 Maine State Invention Convention who received *Best in Show, 1st* place grade 8, 2nd place grade 8, People's Choice and three honorable mentions. In addition, an article co-written with a fellow teacher at the James F. Doughty School and a professor at the University of Maine entitled "Innovative Composite Research Modeled in the Middle School Classroom" was published in the September 2013 issue of *Science Scope*.

Denial of Catastrophic Risks

[This excerpt is from an editorial of the same name by Martin Rees that appeared in the March 8, 2013, issue of *Science*.]

The main threats to sustained human existence now come from people, not from nature. Ecological shocks that irreversibly degrade the biosphere could be triggered by the unsustainable demands of a growing human population. Fast-spreading pandemics would cause havoc in the megacities of the developing world. And political tensions will probably stem from scarcity of resources, aggravated by climate change. Equally discouraging are the imponderable downsides of powerful new cyber-, bio-, and nanotechnologies. Indeed, we're entering an era when a few individuals could, via error or terror, trigger societal breakdown.

Some threats are well known. In the 20th century, the downsides of nuclear science loomed large. At any time in the Cold War era, the superpowers could have stumbled toward Armageddon through muddle and miscalculation. The threat of global annihilation involving tens of thousands of hydrogen bombs is thankfully in abeyance, but now there is a growing concern that smaller nuclear arsenals might be used in a regional context, or even by terrorists. We can't rule out a geopolitical realignment that creates a standoff between new superpowers. So a new generation may face its own "Cuba," and one that could be handled less well or less luckily than was the 1962 crisis.

What are some new concerns stemming from fast-developing 21st century technologies? Our interconnected world depends on elaborate networks: electric power grids, air traffic control, international finance, just-in-time delivery, and so forth. Unless these are highly resilient, their manifest benefits could be outweighed by the catastrophic (albeit rare) breakdowns cascading through the system. Social media could spread psychic contagion from a localized crisis, literally at the speed of light. Concern about cyberattack, by criminals or hostile nations, is rising sharply. Synthetic biology likewise offers huge potential for medicine and agriculture, but in the sci-fi scenario where new organisms can be routinely created, the ecology (and even our species) might not long survive unscathed. And should we worry about another sci-fi scenario, in which a network of computers could develop a mind of its own and threaten us all?

Some would dismiss such concern as an exaggerated jeremiad: After all, societies have survived for millennia, despite storms, earthquakes, and pestilence. But these human-induced threats are different—they are newly emergent, so we have a limited time base for exposure to them can't be so sanguine that we would survive them for long, or that governments could cope if disaster strikes….

Research Experiences for Teachers
Benefits, Research and the Development of Middle School Curriculum Resources

Tracy Vassiliev [NEST '13] & D. J. Neivandt [University of Maine]

Gathering resources for teachers that help to effectively convey science, technology, engineering and mathematics (STEM) practices to middle school and high school students can often be arduous. Wenglinsky (2000) found that when teachers are skilled at implementing hands-on experiences in the classroom, and also trained in laboratory skills, there is a significant increase in student achievement. *A Framework for K-12 Science Education*, released by the National Research Council, emphasizes that "learning about science and engineering involves integration of the knowledge of scientific explanations (that is, content knowledge) and the practices needed to engage in scientific inquiry and engineering design." Hence, to better prepare teachers and improve student outcomes, the National Science Foundation (NSF) supports a program whereby teachers may perform research on various NSF funded projects. The Research Experience for Teachers (RET) program is designed to provide STEM-related research experiences for K-12 science educators. The goal of the RET program is to "enhance the professional development of K-12 science educators through research experience at the emerging frontiers of science in order to bring new knowledge into the classroom (NSF, 2012)."

Tracy Vassiliev [NEST '13] took advantage of two different RET programs at the University of Maine. In 2004, she participated in the RET *Sensors!* program where she investigated heavy metal concentrations within lobster tissue. Her results were shared at the 2005 Massachusetts Lobstermen's Association Conference as well as at the 2005 National Shellfisheries Association Conference in Philadelphia, PA. The RET *Sensors!* summer program allowed this middle school science teacher to work in a laboratory and use some high technology equipment, including a microwave acceleration reaction system (MARS), an inductively coupled plasma atomic emissions spectrometry (ICP) and a flow injection mercury system (FIMS). This experience did not translate directly to the classroom but the experience indirectly manifested itself in a more confident and prepared teacher/scientist. According to Sterling (2004), "well-prepared teachers are more likely to remain in the (teaching) profession. Additionally, research indicates that well-prepared teachers have the largest impact on high student achievement."

The Forest Bioproducts Research Institute (FBRI) at the University of Maine is another research group with an ongoing NSF funded RET as well as Research Experience for Undergraduates (REU) programs. The REU students (college undergraduates from around the US) work on ten-week-long research projects associated with one of the three guiding themes of the FBRI (Table 1). Instead of having the RETs work in a laboratory, they work in parallel with all the REUs to distill their science and engineering research into lessons and laboratory investigations that convey the STEM principles in meaningful ways to middle school students.

The three guiding themes are as follows: • Theme I—Promote Forest Health for a Stable Bio-Economy • Theme II—Understand and Separate Wood Components • Theme III—Create and Commercialize New Bioproducts

Table 1: The three guiding principles of the UMaine Forest Bioproducts Research Institute

A collection of FBRI related classroom investigations are posted on the FBRI Teachers' blog (http://fbri.edublogs.org). These activities are not activitymania, a term used to describe "a collection of prepackaged, hour long (or less), hands-on-activities that are often disconnected from each other (Moscovico & Nelson, 1998)." Rather, these laboratory experiences were developed in light of the *National Research Council's Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and will all be aligned with the Next Generation of Science Standards. Furthermore, the activities are connected to one of Maine's most prized natural resources, trees. The activities serve as an extension of several common classroom laboratory experiments in a way that meaningfully infuses the practices of science and engineering.

The effectiveness of some of these inquiries was the subject of a research investigation where teachers at three regional middle schools in Maine piloted four inquiry activities featured on the FBRI Teachers' blog, with the assistance of the University of Maine's 2009 - 2010 Middle School Collaborative. The idea was to quantitatively assess if these FBRI-related investigations impacted student content knowledge. The overall study included 288 middle school students. The three middle schools piloted investigations on wood composites, tree extracts, tree metrics and tree informational brochures. Each student was given a pre-assessment of applicable curriculum content. At the completion of the research activity, students were given a post-assessment survey. All assessments were levied employing the online Survey Monkey tool. The study demonstrated that the FBRI-related inquiry activities tested, significantly improved student science content knowledge (Table 2).

Content Area Science Survey Questions

Content Area	N	Number of Questions	% Improvement	% Significant Improvement (P=0.10)
Wood Composites	44	5	80%	60%
Tree Extracts	150	5	100%	80%
Tree Metrics	32	5	100%	100%
Tree Info	62	5	100%	80%
Total	288	20	95%	80%

Table 2: This table shows the number of students, content questions, the percent of improved answers on the post survey questions as well as the percentage of significant improvement (P=0.10).

Further, it was found that after middle school students participated in the FBRI-related inquiry activities, they were significantly more likely to attribute certain characteristics (being creative, making mistakes, collaborating, using mathematics and continuing to learn) as common traits seen in scientists (Figure 1). In addition, students were less likely to say that all scientists work in laboratories, a common misconception. Finally, when asked if scientists perform experiments to prove what we already know, approximately 35% of students agreed, while 50% of students disagreed, thus supporting the need for more inquiry activities in the science classroom (Vassiliev, Bernhardt, Littlefield, Hayes, Campbell & Neivandt, 2010).

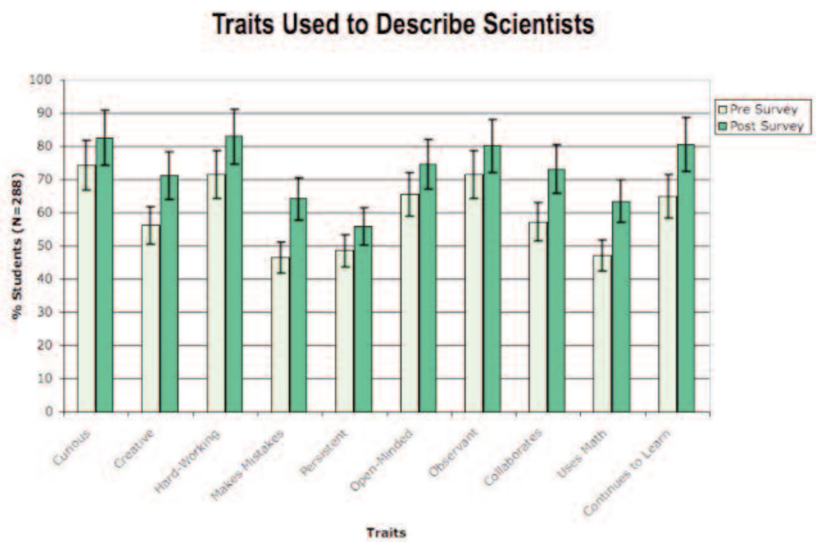

Figure 1: Histogram of pre and post student survey responses presented as the percentage of students that selected certain traits to describe scientists (P=0.10).

All of the FBRI-related investigations, including the investigations described in the study above, are outlined in detail on the FBRI Teachers' Blog site (http://fbri.edublogs.org). The wood composites investigation is also due to be published in the National Science Teachers Association's *Science Scope* journal in September, 2013.

For further information, the aforementioned FBRI blog provides in-depth science investigations and REU and professor interviews. The authors would appreciate constructive criticism and questions. If teachers elect to implement any of the FBRI activities the authors would be most appreciative of any and all feedback, which can be sent to tvassiliev@bangorschools.net.

RET programs are offered every summer at universities and colleges all over the country. One of the many benefits of being a NEST teacher is that we received special consideration for the RET opportunities offered at MIT. As middle and high school educators, we have participated in many professional development workshops and presentations throughout the years, but NOTHING compares to the professional development you gain from a STEM RET experience. The research can be challenging and frustrating, but also extremely exciting. The experience will reinvigorate you as an educator and this heightened passion for STEM will most definitely resonate with your students and, possibly—if we are lucky, be infectious.

Acknowledgements:

The authors gratefully acknowledge the following teachers who assisted in the piloting of the inquiry activities: E. Hayes and K. Littlefield of the Troy Howard Middle School in Belfast Maine; J. Campbell of the Leonard Middle School in Old Town Maine; and P. Bernhardt of the James F. Doughty School in Bangor, Maine.

The RET *Sensors!* program supported by National Science Foundation grant NSF0401439.

The FBRI work reported in the present article was supported by National Science Foundation grants EEC-1063007 REU Site: Explore It! Building the Next Generation of Sustainable Forest Bioproduct Researchers, EEC- 0648793 REU Site: Explore It! Building the Next Generation of Sustainable Forest Bioenergy Researchers, and their associated RET Supplements.

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Solving Stoichiometric Problems

Avi Ornstein [NEST '89]

Stoichiometry is the relation between quantities of two substances involved in a chemical reaction. An example might be: How many grams of hydrochloric acid are required to react with 25.0 grams of calcium carbonate? Calcium carbonate is reacting with hydrochloric acid, which is a chemical reaction. You have a measured amount of calcium carbonate and you are asked to find how much hydrochloric acid is needed, which are two quantitative measurements. This is a stoichiometric problem. I find the following process makes solving stoichiometric problems easier.

The process works when the quantities are mass (grams), moles or volume (liters) of a gas at STP. If the given quantity is not one of these three, it must be converted before starting the process. If the unknown quantity is not one of these three, you must solve for one of these and then convert the answer to the desired form.

The first step that is required is expressing the reaction as a balanced chemical equation. In this case, the equation is $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$. The rest of the problem is built around the equation.

The second step is to record the given quantity above the chemical in the equation. In this case, 25.0 g is written above $CaCO_3$.

$$\overset{25.0\text{ g}}{CaCO_3} + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

The third step is to record the unknown, with its unit, above the chemical in the equation. In this case, x g is written above HCl. While in this case, both quantities are on the left side of the equation, they can actually be anywhere, depending on the individual problem.

$$\overset{25.0\text{ g}}{CaCO_3} + \overset{x\text{ g}}{2HCl} \rightarrow CaCl_2 + H_2O + CO_2$$

The fourth step is to record the corresponding measurements beneath each chemical. If there is nothing above the chemical, this means there will be nothing below. If the unit is moles, the coefficient in front of a chemical denotes the number of moles, with the absence of a coefficient representing one mole. (As a note, these numbers are exact and do not affect significant digits in the answer.) If the unit is gram, you enter the product of the coefficient times the chemical's gram molecular weight (GMW) or molar mass. If the unit is liters, you enter the coefficient times 22.4 L, which is the volume of one mole of any gas at STP. (If both quantities are volumes of gases, it is not necessary to have the conditions be at STP, as the conversions to and from STP would cancel each other out.)

In this case, both quantities are in grams. The GMW of $CaCO_3$ is 100.1 g. The GMW of HCl is 36.5 g. The latter amount is doubled, since there are two moles of HCl in the equation. This gives the HCl a mass of 71.0 g.

$$\underset{100.1\text{ g}}{\overset{25.0\text{ g}}{CaCO_3}} + \underset{71.0\text{ g}}{\overset{x\text{ g}}{2HCl}} \rightarrow CaCl_2 + H_2O + CO_2$$

The fifth step is to set up the proportion that is visible. The units on top and bottom cancel out, so you have a simple mathematical equation:

$$25.0/100.1 = x/71.0$$

You solve for x (17.7) and you find the unit and chemical by referring back to the equation. The unit is after the x and the chemical is below it. Therefore, the answer to this problem is 17.7 g HCl.

If you are given quantities of both reactants, you need to find the limiting reactant to be able to solve the problem. For example: If 45.0 g of $CaCO_3$ react with 0.400 L of 2.50 M HCl, what volume of CO_2 would be produced at STP?

The quantity of HCl must first be converted, since molarity is not one of the three acceptable units. Since molarity is moles per liter, multiplying (0.400)(2.50) gives 1.00 moles HCl. You then follow the first four previously described steps.

$$\underset{100.1\text{ g}}{\overset{45.0\text{ g}}{CaCO_3}} + \underset{2\text{ mol}}{\overset{1.00\text{ mol}}{2HCl}} \rightarrow CaCl_2 + H_2O + \underset{22.4\text{ L}}{\overset{x\text{ L}}{CO_2}}$$

To find the limiting reactant, you divide the numerator by the denominator for each reactant chemical (those on the left side of the equation). For $CaCO_3$ you get 0.44955…while you get 0.5 for HCl. Whichever answer is smaller is the limiting reactant. In this case, that is $CaCO_3$, meaning some HCl will not have reacted. You use the limiting reactant in solving the stoichiometric problem. In this case, the answer is 10.1 L CO_2.

Remind the class that these stoichiometric results are theoretical. They reflect what the quantities would be if the reactants reacted completely. If you do an actual lab, the ratio of the actual result to the theoretical result (what they get by doing the stoichiometric problem) yields the percent yield.

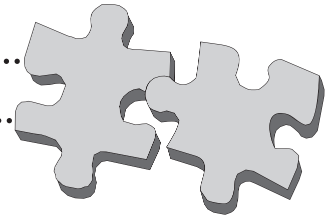
I find that this makes sense to the students and it makes it easier to solve. However, it is important to stress the need to be careful in carrying out computations. I find the biggest single problem is careless errors, whether in finding the GMW of a chemical or entering data into a calculator.

Homework

[This excerpt is from a student voice article by Dan M. Chu that appeared in the March 2013 issue of *Phi Delta Kappan*.]

There are two types of homework: good homework and bad homework. Good homework enriches students' educations. It not only reinforces what they learned for the day, but also builds on the groundwork laid by the day's lesson. Bad homework, on the other hand, does nothing more than force students to grind through more of the same thing they already spent hours on in school. Although there is a saying that practice makes perfect, there is a limit to how much practice one can do. Twenty to 30 algebra problems a night is manageable; assigning 100 of them does not help the student. Busy work only forces students to divert valuable time from more productive endeavors, such as sports and extracurricular activities.

PUZZLE CORNER



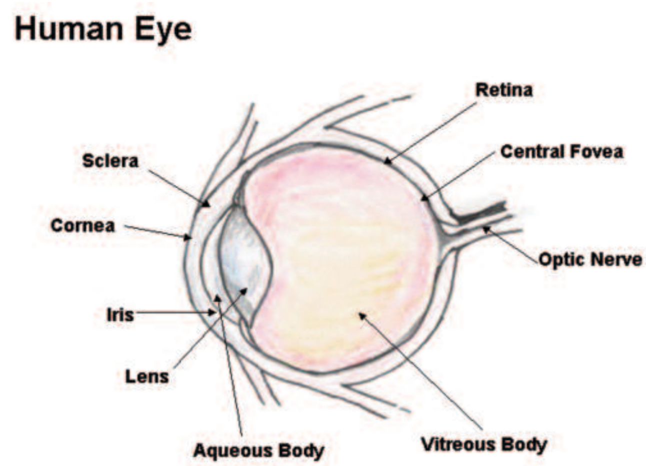
#1) Using a marker, crayon or colored pencil, draw a circle about the size of a nickel and color it in solidly. Place this piece of paper over a second sheet that is blank. Stare at the circle for 30 to 40 seconds and then remove the top sheet. What do you see on the second sheet? Why?

#2) If you stare forward and a colored disk is slowly moved into your field of vision, why can the color not be recognized when the disk is first detected?

Solutions to the previous problems:

#1) The question did not ask what color you see, which is green. Instead, it asked what color grass is, which is red. Light contains a full spectrum of color. When it hits a surface, some wavelengths (colors) are absorbed and others are reflected. The colors that reach our eyes and are interpreted by our brain are the colors that were **not** absorbed. If a surface reflects all light, we see white, which means it is black. If it absorbs all light and reflects none, it is white, and we see black. To get a sense of what color surfaces are (if that catches your curiosity), look at the negative of a color photograph.

#2) In our eyes, the nerves from each rod and cone are attached to the inside of the eye. They come together and exit at the optic nerve. There are no eye cells at this point, so a blind spot exists. Our brain "paints in" this spot to match the surrounding image. Thus, when the circle is in this point, you "see" plain white paper!



NEST Teacher of the Year Awards

Dr. Beate Brase and Andreas Boelter—both from Germany—were named the 2013 NEST Teachers of the Year. The award celebrates members of our community who have promoted science, engineering and technology in and outside the classroom in an extraordinary way. Both made the trip across the Atlantic to receive their awards at the closing ceremony of the 2013 SEPT week.

Dr. Beate Brase teaches 10- to 18-year-old students in Hannover, Germany. Her profound knowledge and enthusiasm are what motivates and enables her students to take on challenges and learn from extraordinary projects. The activities she's led have ranged from collaborating with the European Space Agency and exploring the idea of a "Greenhouse in Space" to participating in important science competitions—including one that rewarded her students with first-place recognition from the Chancellor of Germany. Dr. Brase has established a lab in her school, organized study groups and formed partnerships with universities and companies to create learning opportunities outside the classroom and in the wider community. With these and many other programs she's initiated, her students have made great commitments to continue trying new activities—even during their leisure time (and her leisure time, of course!).

Andreas Boelter is a respected, well-liked and exceptionally knowledgeable teacher of biology and chemistry at Martino-Katharineum high school in Braunschweig, Germany. Andreas Boelter sees the discovery of phenomena by experimentation as one of the keys to making young people engaged and interested in science at school. He's also found that connecting his students to research professionals and opportunities in his community can draw students into the areas of science that excite them.

Andreas has taken his students to visit local science and technology companies, entered his students in local competitions and organized science clubs and a lecture series with speakers from research institutes and businesses. One of Andreas's current projects is the creation of a program called Experts in Schools, which brings STEM professionals into high school classrooms all over Braunschweig—local teachers can connect to the experts through a website he's developed: www.experten-in-die-schule.de. Andreas also offers workshops for teachers and, in collaboration with the MIT Alumni Club of Germany, is involved in bringing a SEPT-like program to Germany this year.

Nominations for the 2014 Teacher of the Year will be accepted starting in February 2014.

Continued from page 1 "Co-Chair Report"

Our schools and teachers are being asked to educate but are being evaluated by how well they train. This is manifested in the students by their assumption that their assigned goal is to find the one correct answer to a problem and to show they have memorized that solution. Learning becomes the collecting of "facts," as defined by their textbooks and their teachers. As educators, we need to facilitate the "education" of our students, rather than providing training activities in our schools.

This brings me to the focus of this essay. Too often, our students do not recognize the important role that failure can play in an experience that is truly educational, when, in fact, school is the best place to make mistakes. Why do students take easy courses in high school? It has been the concern of NEST that too many students avoid challenging subjects like science, mathematics or engineering because they fear that their grade point might suffer. Our students are smart; if they perceive they are being judged on their successes alone, they will avoid demanding studies that may cause them to get low grades or to experience failure. If the only standard of evaluation is the ability to always do things the "right" way, there is no room to be creative, to innovate or to effect change. As STEM educators, we know that making unintended mistakes is a critical part of scientific endeavor and that, in most of our lives, we learn more from our failures than from our successes. The goal is not to vigorously avoid mistakes, but to learn and not repeat them. What is often needed in our society is a sharing of what we learn from mistakes rather than just focusing on success. Yet there is a tendency for people to hide their mistakes. We have all attended workshops at which our colleagues share what has worked for them, but how often have you heard someone tell what didn't work? A learning opportunity has been lost. When one of the goals of a curriculum is to give students the benefit of the knowledge of others so they can avoid "reinventing the wheel," have the students been deprived of the challenge process so necessary to deal with our largest problems? If the outcomes of classroom "lab" activities are predetermined, is this true inquiry? If all activities are too "accessible," failure has been avoided, but a learning opportunity may have been lost. Learning often comes from things that were hard or difficult to deal with. Easy tasks rarely teach; challenging ones do.

As teachers, we should be sharing our mistakes with our colleagues as well as our successes and encouraging our students to expect mistakes. The crime is not to make mistakes, but to refuse to learn from them. There are numerous examples in the history of science in which mistakes were ignored for years after they were identified. It took twenty-five years before the British and American medical establishments stopped using prenatal x-rays on pregnant women, despite persuasive data that it was related to infant deaths. Remember the Brontosaurus? It was a creature that never existed but for years remained in the literature. How many of our textbooks contain mistakes? There is a little book in my home library called *The Road to Success is Paved with Failure*. Hundreds of people well-known to us had major failures in their lives, and the lessons learned from how they handled them need to be part of our education system.

Margaret Heffernan, entrepreneur, CEO, writer and keynote speaker, shared her motto on the NPR TED Radio Hour: "Let's not play the game, let's change it!"

> "We do bring children up to imagine that there is a right answer and that intelligence is about knowing that right answer. And therefore, if you get a wrong answer, you are stupid. So what we do is teach people not even so much to have a passion for the right answer, but to have great talent for second-guessing what everyone wants the answer to be. So you see this is the workplace a lot. Which is, if I ask a question of a team of people, a very large proportion of them instead of really thinking about the problem, think "What does the boss want the answer to be?????" That is incredibly uncreative and shuts down the possibility for superior answers. So I think our fear of mistakes hugely impedes our creativity.
>
> "I have sometimes worked with companies and suggested they have an award for the best mistake, which is essentially not the stupid mistake, and obviously not the mistake you make twice because that shows you are not learning, but the mistake that offers the greatest amount of insight and thus the largest amount of improvement. If you see the top people acknowledging mistakes it makes it much easier for everyone else to acknowledge mistakes."

We are the "top people" in the classroom. Let's not be afraid to be "dummies!" Let's make, and allow our students to make, many mistakes and, in the process, create the opportunity for true education.

Recommended Reading

[The following articles are highly recommended to be read, by both those reading this newsletter and also appropriate students.]

Editors of *Scientific American*; "The Spies above Your Backyard"; Scientific American; April 2003; p. 12.

Choi, Charles Q.; "Bug vs. Superbug"; *Scientific American*; August 2003; p. 24.

Colvin, Richard Lee; "A Rocky Future for School Reform"; *Phi Delta Kappan*; December 2012/January 2013; pp. 66-67.

Desimone, Laura M.; "Reform before NCLB"; *Phi Delta Kappan*; May 2013; pp. 59-61.

Dunn, Rob; "Getting Dirty for Good Health"; *National Wildlife*; August-September 2013; pp. 16-18.

Loftus, Mary; "The Science of Awkward Moments"; *Reader's Digest*; September 2013; pp. 113-119.

Marx, Patricia; "Mentally Fit"; *The New Yorker*; July 29, 2013; pp. 24-28.

O'Donnell, Erin; "Buffering the Sun"; *Harvard Magazine*; July-August 2013; pp. 36-39 & 75.

Pogue, David; "The Last Thing You'll Memorize"; *Scientific American*; August 2003; p. 32.

Serendipity

"Where observation is concerned, chance favors only the prepared mind."
—Louis Pasteur, 1854

[Despite the clearly organized, sequential pattern of the "scientific method," many great advances in science have NOT followed that pattern. They were due to tangential aspects of the research or accidental discoveries that were noticed by researchers with prepared, observant minds. This column shares such fortuitous accidents with you so that they then may be shared with others—especially students—to gain a better, more honest picture of how science has progressed. Perhaps it may alter their attitude in the lab, looking at what actually occurs, rather than just looking for what they expect will happen.]

The distillation of wine (increasing its concentration) was at least known in ancient Greece and Rome and may even go as far back as ancient Babylon. This concentrated form of alcohol was first used as an antiseptic and an anesthetic. Arab alchemists experimented in methods of making these medicinal spirits, and their processes were passed on with the expansion of the Islamic world, reaching Spain and Italy by the 8th century. From there, it expanded northward into Europe. The method that is commonly used today is credited to the Dutch, first appearing in the 12th century. It was the norm two centuries later.

Early in the 16th century, a Dutch trader invented a way to ship much more wine in this concentrated form. While it could later be diluted with water, this process allowed more product to be shipped in the limited cargo area, and it also may have cut down on the taxes, which were based on volume rather than concentration. Most of the water was boiled off the wine and it was then stored in wooden casks.

In addition to removing water, the distillation process led to both the formation and decomposition of many aromatic compounds. Pigments, salts and sugars, which are not volatile, remained behind and it also extracted chemicals from the wood in which it was stored. The resulting alcohol had a distinct taste of its own very different from that of the original wine. In the modern process, caramel is often added to give the color that would result from long storage in wooden casks.

The Dutch name for this alcoholic beverage was *brandewine*, which means "burned wine." In English, the word has been shortened to *brandy*.

Fracking Brine

[These excerpts are from an article by Marian H. Rose that appeared in the March 15, 2013, issue of "The Journal News" which is published in Westchester County, New York.]

…The brine and flow-back/produced water from vertical gas drilling is already being spread, facilitated by the state Department of Environmental Conservation issuing beneficial-use determinations to municipalities. More would be coming from wells in New York if horizontal hydrofracking is approved. Both are known to be highly contaminated with salts, heavy metals and radioactive materials.

…These elevated levels of radium, specifically radium-226, have been confirmed by the DEC in 11 wells that showed levels of radium-226 that exceeded the maximum contaminant level for water.

This highly radioactive water mixed with heavy-salinity brine from the wells will be a threat to our future health if spread on our roads. Ra-226 has a half-life of 1,600 years, or about 80 generations. According to the USGS report, it takes an additional 10 half-lives "for a radioactive element to decay to negligible quantities." From a human point of view, this is forever! As an illustration, the lab notebooks used by the Curies, the discoverers of radium, still cannot be safely handed over 100 years later.

This dangerous material, if used on our roads for de-icing purposes, will be further spread through car and truck tires onto neighboring roads, irrespective of town or county limits, and onto private driveways and into garages. Road brine runoff during storm events can enter our streams, wetlands, recharge areas, aquifers, lakes and ponds. From there, it can easily enter our waste supplies and food chains….

The Science Pipeline

[This excerpt is from an article by Jeffrey Mervis that appeared in the July 20, 2012, issue of *Science*.]

The metaphor of a leaky pipeline is a fixture in discussions of whether enough U.S. students are pursuing careers in science and engineering. And scholars have explored in great detail why so many who profess a passion for science lose the inclination as they move through the education system.

However, a new book on the over-all health of the U.S. scientific enterprise argues not only that the pipeline isn't leaky, but that it's the wrong metaphor. "There is little evidence that science suffers a 'leaky pipeline' during the college years that disproportionately steers students away from scientific fields and toward non-scientific studies," write Yu Xie of the University of Michigan, Ann Arbor, a sociologist and longtime analyst of the scientific workforce, and Alexandra Killewald, his former doctoral student, who this month joined the faculty at Harvard University.

Xie and Killewald argue that the pipeline paradigm ignores two important variables: students who obtain an undergraduate science degree after switching from a non-scientific field, and those who drop out of school before earning any degree. Those omissions, the authors assert, make the pipeline a fatally flawed description of a system that they believe is actually doing a pretty good job of meeting the country's need for scientific talent.

While that conclusion goes against the accepted wisdom, experts find the new book persuasive….

Nothing and Everything

Avi Ornstein [NEST '89]

"Our topic is nothing. By definition, nothing does not exist, but the concepts we have of it certainly exist as concepts….The closest a mathematician can come to nothing is by way of the null (or empty) set. It is not the same thing as nothing because it has whatever kind of existence a set has, although it is unlike all other sets. It is the only set that has no members and the only set that is a subset of every other set….The null set denotes, even though it does not denote anything. For example, it denotes such things as the set of all square circles, the set of all even primes other than two, and the set of all readers of this department that are chimpanzees."*

The zero symbols developed in India in the first few centuries of the post-Christian era. It also arose in Mayan culture. In the thirteenth century, Ch'in Kiu-shao was the first Chinese mathematician to give a separate symbol (a circle) for zero. John Wallis (1616-1703) was the first to explain with any completeness the significance of zero, and he also introduced our present symbol for infinity. Leibniz was the first to consider the concept of the null set. The word 'zero' probably comes from the Latinized form 'zephirum' of the Arabic word 'sifr', which in turn is a translation of the Hindu word 'sunya', meaning void or empty. The Arabic 'sifr' also was introduced into Germany in the 13th century by Nemorarius as 'cifra', from which we have obtained the word 'cipher'.

The null set is symbolized by Ø. It is not to be confused with 0. Zero is a number that denotes the number of members of ?. The null set denotes nothing, but 0 denotes the number of members of such sets, for example the set of apples in an empty basket. The set of these nonexistent apples is Ø, but the number of apples is 0.

If you start with the null set, Ø, you have nothing. You can then consider the set containing the null set, {Ø}, which has one entry. In similar manner, you can consider another set that contains both the null set and the set containing the null set, {Ø; {Ø}}, which has two entries. Continuing along this pattern, you can create a set that contains the null set, the set containing the null set and the set that contains both the null set and the set containing the null set, {Ø; {Ø}; {Ø; {Ø}}}, which has three entries.

You started with nothing, but if you continue in this manner, you can create the entire set of positive integers. From there, you can obtain all—or nearly all—numbers!

It is also possible to make much of nothing, both literally and figuratively. The absence of water or air can cause death. Legally, the failure to act can be a crime. If you are leaning into a strong wind and it suddenly stops, its absence can cause you to fall over. We continuously depend on the various holes in our body system to function and to remain healthy. Similarly, the absence of electrons in metallic bonds makes it possible for a current to be carried.

Two exchanges in *Through the Looking Glass* by Lewis Carroll involving the White King are a beautiful play on our language:

White King: …tell me if you can see either of them.
Alice: I see nobody on the road.
White King: I only wish I had such eyes. To be able to see Nobody! And at that distance too! Why, it's as much as **I** can do to see real people, by this light!

White King: Who did you pass on the road?
Messenger: Nobody.
White King: Quite right, this young lady saw him too. So of course Nobody walks slower than you.
Messenger: I do my best. I'm sure nobody walks much faster than I do!
White King: He can't do that, or else he'd have been here first.

Going further, Sherlock Holmes solves the case of *The Hound of the Baskervilles* by noting the fact that the hound did nothing one night. In a similar vein, Monty Python's spoof on Holmes—*The End of Civilization (As We Know It)*—points out how the fiend will stop at nothing, so they must not do anything.

When mathematicians try to make the final jump from lots of things to everything, however, they find that they cannot make it. "Everything" is self-contradictory and therefore does not exist! A finite set, with n elements, must have 2^n subsets. For example, let us suppose that n = 3. We can label the elements as A, B and C. In this case, $2^n = 2^3 = 8$. The eight subsets are Ø; A; B; C; A, B; A, C; B,C; and A, B, C. Therefore, a set containing "everything" would include all of its subsets, and it is impossible for n to be large enough to equal or exceed 2^n.

One rule of math that everyone is taught is that you cannot divide by zero. If you try doing this with a calculator, you get a message telling you that this is invalid. Why is such the case?

Suppose that you had twenty-four stones in a box. If you remove twelve at a time, it would require two steps. That is, 24/12 = 2. If your remove eight at a time, it would take three steps (24/8 = 3). Likewise, taking out four at a time requires six steps (24/4 = 6) or taking out one at a time takes twenty-four steps (24/1 = 24). If, however, you remove zero stones at a time, you run into a problem. After a hundred steps, there are still twenty-four stones in the box! The same is true after a million steps or a billion steps or however many as you select to try. The box will never be empty. This is why you cannot divide by zero.

If we divide by infinity, the answer would seem to be zero. But this would mean that every number is the product of zero and an infinity. In actuality, every number is the product of an infinity and an infinitesimal number. An infinitesimal number is the reciprocal of an infinite number.

Most of the predecessors of the late 19th century mathematicians either had no conception of the natural numbers as forming an infinite class or they rejected it. A notable exception was Galileo. For instance, he observed that the squares of the integers are "equal" in number to the integers themselves. Leibniz, although aware of a similar type of correspondence, concluded that "the number of all natural numbers implies a contradiction." Even Gauss maintained that "the infinite is merely a way of speaking."

Suppose that there are four people: A, B, C and D. In half the allotted time, A puts discs labeled 1 and 2 into a jar, and B takes out number 1. In half the time that remains, A puts in discs 3 and 4 and B takes out number 3. Again, in half the time that remains, A puts in 5 and 6 and B takes out number 5. This is continued at an ever-accelerating rate until the time runs out.

Simultaneously, in the first half of the allotted time, in a separate jar, C first puts in a set of discs labeled 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10, while D removes disc number 1. In the second time period, C puts in discs numbered 11 through 20 while D takes out number 2. In the third time period, C puts in discs 21 through 30, and D takes out number 3. This also continues until the time runs out. Which jar will have more discs in it?

Discs were added to the second jar by Cat ten times the rate A is adding them to the first jar. B and D are removing discs at the same rate from each jar. However, the answer is that more discs are in the first jar! While all numbers entered it, only odd numbers were removed, so it contains an infinite quantity of discs with even numbers. The second jar is empty! While C was putting them in at ten times the rate that D was removing them, all integers were added and all digits were removed. This displays the complexity of infinity.

Infinity leads to many other interesting results. The following never-ending sequence is another example:

1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 - 1 + 1 …

It can be expressed in two different ways:

(1 - 1) + (1 - 1) + (1 - 1) + (1 - 1) + (1 - 1) … = 0

1 + (1 - 1) + (1 - 1) + (1 - 1) + (1 - 1) + (1 - 1) … = 1

Euler found that applying set formulas to infinite processes produced interesting results. The 19th century effort to inject rigor into math was brought about by an accumulation of such absurdities. As a closing point, it was Pascal who said, "What is man in nature? A nothing in comparison with the infinite, an all in comparison with the nothing, a mean between nothing and everything."

"I'm beginning to understand eternity, but infinity is still beyond me."

Note: This cartoon by Sidney Harris originally appeared in 1973 in American Scientist.

*Martin Gardner; "Mathematical Games"; Scientific American; September 1976.

Worthwhile Websites

The Global Context of Practice and Preaching: Do High-Scoring Countries Practice What U.S. Discourse Preaches
http://50.57.114.26/documents/gsehd/research/Working%20Paper%20Series/WPS2.3_Engel%20Williams%20Feuer_web.pdf

A student's perspective of how youths learn.
www.youtube.com/watch?v=p_BskcXTqpM

Today's scientific world-view, limiting expertise to narrow fields, has shattered unities inherent in pre-industrial cultures. In the absence of a powerful and moral religious tradition, a vacuum has been created within which bits and pieces of knowledge fly about us. Some are comprehensible, many are not.

— John Todd
"Tomorrow is Our Permanent Address"

Accepting Failure

[These excerpts are from an article by Donna L. Miller that appeared in the February 2013 issue of *Phi Delta Kappan*.]

Conventional wisdom tells us that without the willingness to take risks—including the risk of failure—nothing of significance would ever be discovered. If learning is about failure, then why in education is an F worse than Hester's scarlet letter A?

…Regardless of how thoroughly teachers present a lesson, they can't anticipate and remove every confusion students may experience. Teachers depend on student questions as cues for additional scaffolding, but these questions don't often come. With their expertise, their polished products of research and training, teachers render confusion implausible….

…Students with a fixed mindset see ability as something inherent that needs to be demonstrated. They believe that intelligence is static—they only have a certain amount. Their desire to look smart leads to a tendency to avoid challenges, to give up easily, to see efforts as futile, to ignore useful feedback, and to feel threatened by the success of others….

When students instead have a growth mindset, they understand that intelligence can be developed and doesn't depend on luck or genetics; rather, like a muscle, intelligence grows stronger through exercise. Instead of worrying about how smart they currently are, they work to improve by embracing challenges, persisting in the face of setbacks, learning from constructive criticism, and seeing effort as a path to mastery. They understand that mistakes and confusion will litter their path.

…perhaps we can convey that real learning is about growth and that real growth can be uncomfortable. Learning is hard work, especially when students are urged to question, evaluate, and interpret ideas they're trying to comprehend for the first time. When engaged in these critical thinking processes, one outcome is certain: Learning can rock the core of previous knowing, causing a shift in balance….When learners accept that learning is about transformation and that some discomfort is inevitable, a trip to wobble world will leave them dizzy with new wisdom and experience, not inundated by the sensation of imbalance. No longer worried about failing, learners might let go of the easy answers and find comfort in the questions.

…Because cognitive dissonance has unsettling effects and learning happens in stages, these changes will require time; growth will not occur without error.

Continued from page 1 "MIT SEPT"

discovered how to use MIT Mathlets in the classroom. This is only just a small sample of the flood of ideas and information that occurred as the result of MIT's unique fire hose.

As part of the summer workshop experience, all the participants lived in a dorm on campus. This immersed us in MIT's culture of creativity, innovation, problem solving and, yes, even hacking. *(The word hack at MIT usually refers to a clever, benign and "ethical" prank or practical joke, which is both challenging for the perpetrators and amusing to the MIT community—and sometimes even the rest of the world! http://hacks.mit.edu)*. During the evenings, the group of master teachers from around the world got together to explore Boston, share stories, discuss best practices and plan our hack for our stay at MIT. You can just imagine the energy and creativity was like in a room full of top educators.

Educate…Engage…Inspire… that is what makes MIT's SEPT workshop one of the most powerful professional development opportunities I have ever attended. After my week at MIT, I could not wait to get back to school to share and implement everything I learned. Luckily, this amazing learning experience does not stop here. Having completed the SEPT program, I can now participate in NEST (Network of Educators in Science and Technology). Through this fellowship program, participants stay connected to MIT and continue their learning. Members of NEST are invited back to MIT for a workshop every June, receive the NEST newsletter, obtain information on summer research opportunities, are able to give an annual MIT student recognition award in their school and much more.

I am grateful to the MIT Club of Hartford for giving me the opportunity to attend this unique professional development program. I strongly encourage other educators to seek out their local MIT Alumni Club. Many of these clubs annually select a local teacher and award a scholarship to cover the SEPT course tuition, plus an allowance for incidentals and transportation to MIT. Apply to the SEPT program and experience MIT with its innovation, cutting edge research, resources, passionate professors and entrepreneurial spirit.

Go to http://web.mit.edu/scienceprogram for more information on the SEPT program.

SEPT 2013

Michael Carbone [NEST '12]

This year's MIT Science and Engineering Program for Teachers (SEPT) welcomed a variety of different math and science teachers from across the globe. Participants took part in a multitude of unique learning opportunities across the science and math continuum. Through both hands-on activities and engaging lecture, SEPT 2013 participants heard from a variety of MIT professors and staff about the "awesomeness" of science and mathematics. Most importantly, participants discussed these content-specific implications within their classrooms. This year, the event was both live-tweeted and tracked on the new SEPT website. If you were unable to attend in person, you can still access speaker resources from the website!

For more information, visit http://mitsept2013.weebly.com.

Continued from page 1 "Climate Change Impact"

be protected, not just because it is part of good stewardship but also so that they can take care of us. But even the first step of modeling the effects of greenhouse gas sources and sinks on future temperatures requires input from atmospheric scientists, oceanographers, ecologists, economists, policy analysts, and others. The problem is even more difficult because the very factors that influence temperature changes, such as ocean circulation and terrestrial ecosystem responses, will themselves be altered as the climate changes. With so many potential climate-sensitive factors to consider, scientists need ways to narrow down the range of possible environmental outcomes so that they know what specific problems to tackle.

Researchers have turned to the geological record to obtain ground truth about patterns of change for use in climate models. Information from prior epochs reveals evidence for conditions on Earth that might be analogs to a future world with more CO_2. Projections based on such previous evidence are still uncertain, because there is no perfect analog to current events in previous geologic epochs; however, even the most optimistic predictions are dire. For example, environmental change brought on by climate changes will be too rapid for many species to adapt to, leading to widespread extinctions. Even species that might tolerate the new environment could nevertheless decline as the ecosystems on which they depend collapse. The oceans will become more stratified and less productive. If such ecosystem problems come to pass, the changes will affect humans in profound ways. The loss in ocean productivity will be detrimental for the 20% of the population that depends on the seas for nutrition. Crops will fail more regularly, especially on land at lower latitudes where food is in the shortest supply. This unfavorable environmental state could last for many thousands of years as geological processes slowly respond to the imbalances created by the release of the fossil carbon reservoir. The time scale for biodiversity to be restored, with all the benefits that it brings, will be even longer.

Unfortunately, I view these predicted outcomes as overly optimistic. We are not just experiencing increases in greenhouse gas emissions but also eutrophication, pollution of the air and water, massive land conversion, and many other insults, all of which will have interacting and accumulating effects. The real problem we need to solve in order to really understand how Earth's environment may change is that of cumulative impacts. Although the Paleocene-Eocene Thermal Maximum (about 55 million years ago) is the time period considered to be a reasonable analog to a higher-CO_2 future, the planet was not experiencing these other stressor and climate change simultaneously. So terrestrial species that survive a climate impact alone may face extermination if reduced to a fraction of their natural range through deforestation and habitat fragmentation. Marine species that are mildly susceptible to ocean acidification may not be able to tolerate this condition plus low oxygen levels.

Sometimes the science of cumulative impacts is straightforward—for example, connecting habitats to provide migration corridors in response to sea-level rise brought on my climate change. But even "clear-cut" cases require extra work, more partnerships, and more time to address. Tackling problems of cumulative dimensions is a priority if we are to find viable solutions to the real environmental crises of the coming decades, There is a need for all scientists to rise to this challenge.

Robotics in the Classroom
A Two Way Street—Teaching and Learning

Bob Kahn [NEST '13]

"In a future time, children will work together, to build a giant Cyborg, Robot Parade, Robot Parade, wave the flags that the robots made, Robot Parade. Robot Parade. Robots obey what the children say."

If you have never heard this song by They Might Be Giants, you might enjoy it. You see, many moons ago, depending on your time frame, my daughter Madi (17) and son James (14) would sing along to Robot Parade in their best robotic voices. Little did I know that after twenty years of being a science teacher, my philosophy of learning and teaching would shift such that I would become a robotics teacher as well. I taught my first Robotics course one week after attending MIT SEPT 2013.

Spending the entire week before the course preparing alleviated only a bit of the nervousness that comes with doing anything the first time. How was I to be prepared enough when three of my six students had First LEGO League experience and thus already knew much more than I did? Still, this did not deter me. In fact, my philosophy of teaching and learning has evolved to include me, the teacher, learning with and from my students instead of students *just learning* and me *just teaching*. I believe many teachers are fearful of their students "knowing" more than they do. I have come to embrace and harness student knowledge and expertise in order to increase their learning and empower them. Robotics seemed like a perfect testing ground. Deciding that I was not going to pretend to know everything, I planned to deliberately learn from my students by asking them questions. Puzzled, one kid went home and discussed this strange teacher behavior with his parents. On the last day of the course, the parent informed me that her son ultimately "felt empowered by the fact that [I] valued his knowledge." I cannot think of a better way to increase a kid's desire to learn. Being older and more experienced, I also asked deeper questions about their robot designs and posed other questions to get them to think. To coin a phrase, I call this 'two way street teaching and learning.' This, to me, is what it is all about.

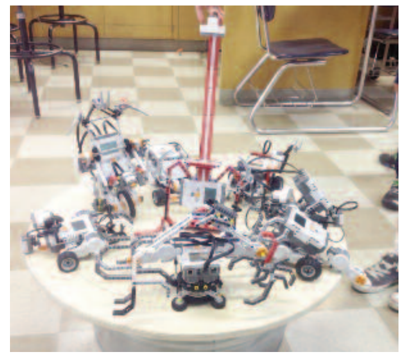
My mindset was in place but what about the room and the equipment. The week before I put up posters, organized the LEGO Mindstorm pieces into trays coded with the names of robots from movies, Wall-E, C-3PO and Sonny and moved the desks out of the way (where they belong). I wrote three rules/procedures on the board which I called "algorithms":

1. **Everyone** has something to contribute.
2. Only use pieces from **your** kit.
3. Respect equipment.

I had already familiarized myself with the NXT software in previous weeks but was still working on some of the challenges for the kids. I did not have all the "answers," but I was becoming aware of many questions. Everything was in place. All I needed were the kids.

On the first morning, I gave Ara, Katie, Jake, Andre, Jackson and Charlie each a brown paper bag containing about twenty various LEGO pieces—a "Breakfast Build," if you will. First challenge: "dump the contents of your bag on the tabletop and build something in five minutes. Go!" I love the sound of LEGOS on a countertop. Surveying, thinking, designing and evaluating all in five minutes. The results surpassed my expectations and can be viewed in this brief video. This activity set a positive tone of exploration and design that lasted the entire week.

Friday arrived too quickly. Being that it was such a small group of enthusiastic kids and that we were together from 8 to 2:30 every day, we got to know each other very well. The kids worked through the fundamentals of building with Mindstorms, using the various sensors and programming with the NXT software. Friday afternoon we invited parents to a Sumobot tournament and a maze demonstration. (Click here and here for two short videos.) Katie and her robot won every contest, including both the Sumobot round robin and elimination tournament and the maze competition.



With the successful execution of my first experience teaching Robotics, here are just a few of the lessons that I learned:

1. Time spent on the front end to prepare and organize was well worth it.
2. A 'resource center' where all of the equipment could be found was very helpful.
3. During competitions, sportsmanship is a must. Whether kids won or lost, they gave each other 'bot-5s', (instead of high-5s).
4. It is difficult to anticipate everything. One pair of students built a robot that was about half the diameter of the Sumobot board. While we came up with a compromise to solve the problem, the two students were not very pleased with having to modify their robot.
5. I need to develop a system of accountability as students progress from one challenge to the next.
6. "Teaching" Robotics was everything I expected it to be. The kids and I engaged in authentic problem solving *together*, resulting in genuine learning and mutual respect. That's what I call 'two way street learning!'

During twenty years of teaching, I have rarely taught in this way, truly as a "guide on the side." Challenging, but exhilarating! In fact, half way through the week, the kids having progressed faster than I anticipated, I threw down the gauntlet and informed them that I was going to build a robot to compete in the Sumobot tournament. Nothing galvanizes kids more than wanting to beat the teacher.

My first taste of teaching robotics was sweet, but teaching 45-minute blocks during the school year will reveal a whole new set of challenges for both me and the students. One plan is to do more creative activities. For the summer course, I was initially not planning on doing the Sumobot competition because I did not want this type of winner/loser event. During the school year course, I would like to create an activity requiring students to work together instead of against each other.

Here's an idea, how about a "Robot Parade"?

Science Education

[These excerpts are from an editorial by Bruce Alberts that appeared on page 249 of *Science* on April 19, 2013.]

… [teachers] have many valuable suggestions for improving education systems. I am also painfully aware of the many past failures that have been caused by not giving the best teachers a strong voice in the public policies that profoundly affect their profession. In the 1980s, the Japanese taught the world that building a better automobile requires listening to workers on the assembly line. More generally, experience shows that actively soliciting advice from those most intimately involved is essential for wise decision-making at higher levels. Regrettably, education is one of the few parts of U.S. society that fails to exploit this fact. Hence, my initial Grand Challenge: "Build education systems that incorporate the advice of outstanding full-time classroom teachers when formulating education policy." A start has been made, but much more remains to be done….

To be competitive in the global economy, businesses need to be able to hire workers who can "think for a living," More specifically, studies reveal that the private sector seeks employees who can apply a capacity for abstract, conceptual thinking to "complex real-world problems—including problems that involve the use of scientific and technical knowledge—that are nonstandard, full of ambiguities, and have more than one right answer." These employees must also have "the capacity to function effectively in an environment in which communication skills are vital—in work groups."* Achieving the revolution in U.S. science education that is called for in the *Next Generation Science Standards* released last week would go a long way toward creating the type of high-school graduates that the private sector needs….Business leadership in the United States often fails to advocate for wise education policies, despite its potential for influence. Hence, my second Grand Challenge: "Harness the influence of business organizations to strongly support the revolution in science education specified in the *Next Generation Science Standards*."

[In 2009] I pointed out that, "Rather than learning how to think scientifically, students are generally being taught about science and asked to remember facts. This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere. Scientists may tend to blame others for the problem, but—strange as it may seem—we have done more than anyone else to create it." College science courses are taught by scientists, and they define "science education," modeling for teachers and adults what should be done at lower levels. Most college faculty have not yet faced up to the urgent need to improve on the standard one-size-fits-all lecture format….Thus, my final Grand Challenge: "Incorporate active science inquiry into all introductory college science classes."

* R. Marshall, M. Tucker, *Thinking for a Living: Education and the Wealth of Nations* (Basic Books, New York, 1993).

STEM Education

[These excerpts are from an article by Jeffrey Mervis that appeared in the April 19, 2013, issue of *Science*.]

Most people agree that the U.S. government could do a better job of managing the $3 billion being spent by a dozen federal agencies on science education, public understanding of science, and the training of future scientists and engineers. But few are lining up behind a White House plan to accomplish that goal.

In a move that surprised science educators, legislators, and even many federal educational officials, President Barack Obama included a radical realignment of STEM…education programs in the 2014 budget request that he submitted last week to Congress….his budget designates three agencies to shoulder the load in four priority areas—the Department of Education in precollege science and math education, the National Science Foundation in both undergraduate and graduate STEM training, and the Smithsonian Institution in STEM activities outside the regular classroom….

Outside observers think it is unlikely that Congress will agree to anything as radical as what the White House has proposed. And mission agencies aren't eager to give up what they are doing….

Leveling the Playing Field

[These excerpts are from an editorial by Marcia McNutt that appeared in *Science* on July 26, 2013.]

According to a recent study, although women in the United States retire at the same age as men, their retirement income is on average 29% less, because they lose ground in terms of their salary and career advancement with each child they rear. Men, as fathers, experience no such penalty. Such family issues affect all women in academia but are more pronounced for women in the STEM disciplines, where women remain underrepresented in many fields….

CWSEM [Committee on Women in Science, Engineering and Medicine] is working to level the playing field for all women in STEM disciplines, whether they are found in academia, in government, or in industry. The committee shares data and expertise, raises awareness about promising programs and proven successes, and builds a community committed to stemming the waste of talent and resources when careers are stunted unnecessarily. When hundreds of thousands of dollars are invested in the training of each STEM graduate student, supporting CWSEM to help find better ways for all women in STEM occupations ultimately reach their true potential is a wise investment.

Next Generation Standards

[These excerpts are from an education forum that appeared on pages 276-277 of *Science* on April 19, 2013.]

Imagine that politicians and the people they represent understood how human activity impacts Earth, including climate. And imagine that they had learned how to evaluate claims, argue from evidence, and understand moods. These understandings and practices are prominent in the U.S. national Research Council (NRC) framework to guide the next iteration of standards for U.S. elementary and secondary school students….

Past educational standards were developed by professional organizations on behalf of scientists and educators and in different subject areas independently, yielding more material than any K-12 school system…could teach well. Now there is a call for "fewer, clearer, and higher" standards.

The CCSS [Common Core State Standards] focus not only on what it will take to become a successful student in higher education but also a successful employee. Broadening the scope in this way, skills and abilities that support civic participation are explicit in the standards….

The math standards take an overdue step toward greater synergy with science by introducing modeling in secondary grades. The math standards define modeling as "the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions." The elaboration of the basic modeling cycle resonates with the writing standards and with the science practices….

In this promising context, science standards have been drafted, working with the NRC framework, that operationalized "inquiry" with eight practices of science and engineering: (i) asking questions and defining problems; (ii) developing and using models; (iii) planning and carrying out investigations; (iv) analyzing and interpreting data; (v) using mathematics and computational thinking; (vi) constructing explanations and designing solutions; (vii) engaging in argument from evidence; and (viii) obtaining, evaluating, and communicating information.

The framework attempted to narrow the number of core disciplinary ideas, although reviewers of draft science standards have said that the volume of content undermines the sense making required by the practices….

Science educators have decried the common practice of reading textbooks instead of doing investigations; the former is still alive and well….It is time to embrace the coherence and learning that can be achieved by making meaningful connections between and among direct experience with science and engineering practices and reading, writing, speaking, and listening….

Historically, the United States had provided limited opportunity to learn science to most of its students and advanced training to a privileged few, focusing on the pipeline for future scientists and innovators without concomitant attention to a science literacy for citizenship. The system needs to be transformed to affirm high standards of accomplishment for all students and to provide resources for all students to reach them….

Science education benefits from the learning sciences; scientists interested in the most effective training of science need to learn from education research. Formal schooling has been criticized as ineffective at motivating and inspiring students and inadequate at recognizing the relation between interest and accomplishment. The NGSS can provide a platform for formal education to become more motivating. May people are inspired by science in informal settings; parallel attention to the NGSS can contribute to "a wide-ranging and thriving ecosystem of opportunities that respond to the needs of children as well as communities." Education and public outreach activities associated with research grants, whether in or out of school, should provide some preparation and inspiration. Local school districts, after-school providers, and informal science institutions need to create a coherent strategy for the regional science learning ecosystem.

This new round of standards development is an opportunity to improve science education that comes around once for each generation. We need to inform ourselves, figure out whether and how we want to get involved, and be intentional about our participation.

Improving Education Standards

[These excerpts are from an editorial by Janet Coffey and Bruce Alberts that appeared on page 489 of *Science* on February 1, 2013.]

…The Framework puts forth a vision of science education that is notable for emphasizing student participation in key science and engineering practices, such as asking questions and defining problems; developing and using models; engaging in argument from evidence; and learning cross-cutting concepts such as energy and matter, cause and effect, and structure and function. To allow room for these in the school day, the Framework stressed the importance of minimizing the number of disciplinary core ideas that standards require to be taught….

…But the sheer volume of content referenced in the Framework moves to the foreground in the NGSS draft and threatens to undermine this promise. Any emphasis on practices requires a science-rich conceptual context, and certainly the core ideas and cross-cutting concepts presented are useful here. However, the draft contains a vast number of core disciplinary ideas and subideas, leaving little or no room for anything else….

The welcome shift in priorities to teaching science and engineering practices along with the content brings an assessment challenge. The NGSS draft document addresses the challenge by delineating many performance expectations. However, current measurements and approaches do not allow these types of performances to be assessed easily; it is much more difficult to evaluate the quality of such engagement than to determine the accuracy of an explanation or a word definition. Urgently needed is a vigorous R&D agenda that pursues new methods of and approaches to assessment. This will be difficult but critically important long-term work. A systematic commitment to the wrong quantitative measures, such as the inexpensive multiple-choice testing of factoids, may well result in the appearance of gains at the tremendous cost of suppressing important aspects of learning, attending to the wrong things in instruction, and conveying to students a distorted view of science. Outstanding scientists must be willing to work side by side with measurement specialists and science educators to develop methods for evaluating what is important to measure, after completing the short-term task of prioritizing and reducing the number of disciplinary core concepts in the new standards.

Bringing Why to Generation Y Science Education: College Preparatory, Honors and AP Biology Use of the Drosophila Virtual Fly Lab

Helen J. Flavin [NEST '10]

In the previous newsletter, the first column in this series discussed how to create assignments that serve to make the student the scientist who must decipher the data and then explain it to the world. Such challenging problems provide today's adolescent an immediate context for why such knowledge is important. Further, the projects harness students' competitive spirit. Engaged students dig deeper, learn more and have fun doing so. Being the scientist while learning the science also promotes development of creative, independent thinkers with sharpened 21st century job skills. This column discusses high school genetics education.

The Drosophila Virtual Fly Lab at http://nemo.sciencecourseware.org/vcise/drosophila is an excellent science inquiry tool for Genetics curriculum. A good resource for background information is www.yale.edu/ynhti/curriculum/units/1996/5/96.05.01.x.html, which also lists Drosophila mutations. Advantages with this virtual lab application include: visual correlations of phenotype and genetic inheritance measured over multiple generations; intuitive understanding of the P, F1 and F2 generations leading to increased understanding of pedigrees and how to follow genetic inheritance with such a tool; reductions of student misperceptions regarding sex-linked inheritance; and multiple possibilities for projects that extend first year biology coverage of genetics.

Although teachers can set up an account for their class, the virtual lab program works well for individual students who log in as guests. The program is very user-friendly. It allows students to purchase flies, perform the mating and then view the flies under the microscope. The program sorts the flies into piles separated by phenotypes. Students can click on a pile to view an individual fly and they are given a summary table of numbers of individuals for each phenotype. The program does have notebook and report capabilities. However, I suggest having students write down the crosses as they perform them. This allows them to immediately generate the Punnett square for the cross and verify that the phenotypic ratios are consistent with their proposed inheritance of the gene. Such analysis drives their decisions on how to set up the next mating. For project extension at the first year biology level and for required AP biology curriculum, the program will allow chi square analysis of results.

One approach for CP or honors biology is that the teacher can use the program to demonstrate or review the genetics vocabulary, Punnett squares and the mathematical analysis of the data. For example, choose a recessive gene (e.g., sepia eyes) and run a mating of sepia eye female crossed with wild type (wt) male. Immediately, students can determine whether the allele is dominant or recessive and must decide why the numbers for the wt males and wt females are almost equal. Instead of telling them how to do the analysis, let them figure it out for themselves. This encourages development and application of analytical skills. There are two general approaches to the analysis. First, one can treat the data as a dihybrid cross for independent traits with one trait being sex and the other eye color. The second approach would be to sum the males and females of a particular phenotype (eye color) to verify the total number of individuals represents the anticipated percentage.

Next, the program allows selection of F1 male and female flies (heterozygotes) for mating. As the flies are growing and developing, students can do the Punnett square and predict the phenotype ratios. Analysis of the fly data allows students visual and mathematical confirmation of the inheritance pattern. Finally, a male F1 fly (heterozygote) can be crossed to a female sepia-eyed fly (homozygous recessive) which covers the test cross which is the genetics test used to verify that an organism is in fact a heterozygote.

Through this example, students now have the tools and the mindset to be the geneticist. Have each one open the program and individually choose one gene where they must determine its inheritance pattern as the class did together for the sepia eye color. For the student, that "hey, I can do this moment" is empowering. Most will choose autosomal genes. However, for the few who choose a gene that is sex-linked or lethal and thus does not follow the expected pattern, just have them carefully document their crosses and data. They have experienced that scientists sometimes find unexpected data and then must seek to find an explanation for it. If the student is willing, you can give him/her a hint and once he/she figures it out, he/she can be the teacher to the class. Another option is for you to use that student's gene choice as the example to teach about that type of inheritance.

The next assignment is to use the virtual fly lab to have the students "discover" in parallel the chromosomal inheritance of genes and sex-linked inheritance. As you know, with this they are essentially repeating Morgan's defining work. The virtual lab allows them to be Morgan making the discoveries instead of memorizing his work! For first year biology, have half the room cross a red-eyed female with a white-eyed male (male and female offspring have red eyes). The other half of the students are to cross a white-eyed female with a red-eyed male (female offspring have red eyes and males have white eyes). Let them discuss and work through their Punnett squares until they reach consensus that somehow a male has to only carry one factor/gene. Next, show them the Drosophila chromosomes either unlabeled or labeled X and Y such as in Fig 1.2 at www.education.com/study-help/article/chromosomes. This visual is enough for them to determine which chromosome has to carry the gene for red eyes. If the answer is not immediately apparent to them, just ask how is it possible for females to have two copies of something, but males only one? This approach to the biology minimizes the possibility for one common misperception regarding sex-linked inheritance. Students who have worked through this analysis will never localize sex-linked genes on the Y chromosome (well, not until they meet that other type of sex-linked inheritance in college level genetics courses). Also, students will understand why the gene designation is X^w for the allele for white eyes!

AP biology students can, of course, approach the same topic with the parental cross red-eyed female with a white-eyed male and subsequent chi square analysis of the F1 by F1 cross (gives ½ males red eyes and ½ males white as expected, but all females red eyes—unanticipated result). The chi square analysis shows that the results are not due to chance alone. Their eventual hypothesis for sex-linked inheritance shows four genotypes for the F2 generation. Students can be asked to use the program (design and analyze appropriate crosses) to demonstrate the red-eyed females in the F2 generation are a heterogeneous population of homozygous dominant and heterozygotes.

How to use the virtual lab for unique projects and assessments? One can have AP biology students serve as mentors or coaches for first-year biology students as they learn the genetics. Bringing writing to the science curriculum, students can be asked to prepare a genetics handbook with their data from the virtual lab discussing: dominant inheritance; recessive inheritance; sex-linked inheritance; and a dihybrid cross. An example for a dihybrid cross for independent traits is tan body and vestigial wings. A third idea is a genetics challenge. Students can be broken into groups, with each group using the virtual lab to prepare a tough genetics question (and, of course, the answer!). Then, you can use these challenging questions for a team challenge (problem solving day) which can also serve as a review for the entire genetics unit.

My AP biology students use the virtual lab for Morgan's work and the handbook as described above. As they are working to complete this, the bonus assignment is for them to find a way to use the virtual lab to explain recombination frequencies and how these are used to map chromosomes. If they work through it and present their work, they receive a full lab's bonus credit. This encourages those who are ready to "discover" for themselves the analysis for the next part of the AP biology curriculum. The virtual lab models well the dihybrid purple eyes, black body fly cross with wild type fly. Students can individually work through all of this. However, if you prefer, you can augment your class lesson with this example. The parental cross is male purple eyes, black body crossed with female wild type. The F1 females are crossed with those male purple eyes, black body. Analysis of the data provides a 6% recombination frequency which, of course, matches what is listed for the Drosophila chromosome.

The virtual lab provides a number of possibilities for extension of first-year biology curriculum. One example is chi square analysis. One resource that provides a succinct introduction to chi square analysis is www.ndsu.edu/pubweb/~mcclean/plsc431/mendel/mendel4.htm. Another project for extension is full analysis of a dihybrid cross with linked traits (e.g., purple eyes and black body). Thus, one can introduce linked genes being inherited together. With the discovery of non-parental offspring types in crosses involving linked genes, students see firsthand the results of meiotic crossing over events. Students can then better appreciate why and how to use such numbers in chromosome mapping. A third extension is that students can be introduced to the idea that some genetic combinations are lethal (e.g., curly wings). Please see the pleiotropy section of the ndsu.edu resource for a brief discussion of how a lethal gene can affect a phenotype ratio.

In summary, this virtual lab can be used by groups to show/illustrate genetics concepts; by students to independently master the concepts and calculations; by students to review before a test; for independent, but guided remedial work; and, most importantly, to challenge students to higher levels of understanding of genetics. This tool allows one teacher to offer variegated assignments so as to be able to challenge each individual student no matter where he/she begins the study of genetics. Finally, for those students with talent and interest, this one virtual lab will allow them the opportunity to master genetics to the college level.

The deadline for publication in the next issue is: **March 1**

Please send articles to:
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Crowdsourcing Brings Real Science into the Classroom

Dawn Jones [NEST '13]

I left the 2013 summer SEPT program at MIT armed with many new ideas for my middle school science classroom in Colorado. One of the most exciting has been the opportunity to involve students in actual research projects through crowdsourcing games developed by research teams at MIT. Dr. Sebastian Seung's work to map neurons and Dr. Sangeeta Bhatia's online game for designing nanoparticles to target cancer cells are exciting projects that can engage even middle-school age students in generating data that may lead to important breakthroughs. At the same time, these opportunities give teachers a chance to help students look at data in new ways and realize that the overwhelming amounts of data now being generated create exciting opportunities for scientists to ask original questions and plumb existing data sets to learn new things.

Dr. Bhatia, who works at the Koch Institute of Integrative Cancer Research at MIT, has introduced an online game called NanoDoc that allows the general public to help her design new nanoparticle strategies towards the treatment of cancer. Students log on at http://nanodoc.org and play a game to design nanoparticles while learning about nanomedicine at the same time. On another part of the MIT campus, undergraduates, working with Dr. Sebastian Seung to map neuronal connections in the brain, developed a game called Eyewire in which players help with the time-consuming task of tracing neuron paths from images generated in research labs. Students log on at http://eyewire.org, practice with some tutorials and then have the chance to contribute to the real work of the lab. While kids engage in the fun of contributing to real research, the research teams are expanding their productivity by harnessing brainpower from around the world.

Both of these efforts are part of the crowdsourcing trend, distributing online problem-solving that engages large groups of people to get a job done. Like other Citizen Science initiatives, including the Planet Hunters work at www.planethunters.org sponsored by Yale and Zooniverse, these two MIT projects give students a chance to feel a part of something larger that is authentic and on-going in the real world. Though not always easy at a middle-school level, I try to find Citizen Science opportunities that link with units of study and then share them with my 7th and 8th grade students and their families on the class website. This year I will also recommend the new MIT projects to students as they start planning projects for our Science & Engineering Fair. One outcome, I hope, will be that students will think more about existing data sources that they might analyze as an alternative to generating new data. Another outcome, even more exciting, is that students may start to think about ways to extend their own reach and power by engaging a larger community in their work.

The school year has only just begun, so I don't have much feedback yet from students, but, as a teacher, I'm excited about the opportunity. We work hard in our classrooms to support students in becoming more effective collaborators and to value teamwork, use technology in authentic and productive ways and become more engaged in pursuing science and technology careers. Toward that end, participating in engaging online crowdsourcing projects to take part in real-time research is an exciting learning tool on all fronts.

Effort

Avi Ornstein [NEST '89]

The effort one puts into what he or she does directly impacts the outcome and, to a large part, decides the future one can achieve. This applies to school as truly as it does to life. At the same time, students must go to school; it is not a choice that is left to them, and this has a direct influence on their effort. As Alexander McCall Smith noted regarding students*, "there were some things that just had to be learned through effort, and she was not sure how popular effort currently was."

Effort can be either internal or external. The former is based on self-motivation while the latter depends on outside forces—parents, teachers and peers. Each form is different. Internal effort is definitely preferable. It is more valuable, having long-term effects on a student. When the effort is based on personal values, it carries on to their future and broadly influences their life. This does not mean that external effort should be looked upon in a negative perspective, as it is a way to assist in attaining a level of internal motivation.

Offering rewards may lead to developing internal effort, and those that have true meaning are potentially more likely to lead to that goal. Meaningful homework is an important component of a good education, as it allows students to reinforce important concepts. I have found that tying rewards to assigned homework can improve the effort offered by my students. One method that has proved fruitful is allowing an index card of notes on tests if no more than two assignments are missed during a unit. More of the students do a higher proportion of the assignments, improving their effort with matching benefits.

I also have a system where students can earn excused homework passes, which ties in well with the previous component. Students can earn such passes by doing enrichment activities** or by identifying errors that I make, either in handouts or at the board. I do not make any intentional errors, but the students learn to pay attention to detail, thereby improving their actual effort. Allowing opportunities for corrections to poor or missed assignment, within clearly set parameters, similarly improves the students' effort, as they do not automatically toss in the towel if a third assignment is missed.

Our school this year initiated final exam exemptions. If students show consistent high quality work throughout the year, they do not have to take final exams. I had convinced my school to follow such a program back when I was in high school and I strongly endorse this choice. Good students work even harder, thereby internalizing their effort via a steady pattern right to the end of the academic year. Finally, offering individual help outside of class also reinforces student effort and is a worthwhile investment of time and energy.

A less direct but perhaps more important way of motivating students is leading by example. Showing effort and concern on your own part multiplies the impact. We need to display the importance of effort in our position as role models. Get work back to students in a timely manner. Do not give assignments that are busy work and let them see the value by paying attention to the work that is handed in. Take advantage of chances, as they arise, to impart your thoughts regarding the importance of effort so that they actually understand the impact it has in your class and on their lives.

As a closing point, consider sharing the following quote of Buddha with your students: "What you are is what you have been. What you'll be is what you do now."

*The Limpopo Academy of Private Detectives, p. 22

**One source of enrichment activities is my website (www.aviornstein.com), which includes a weekly puzzle. The first student in each class to correctly solve the puzzle earns an excused homework. The submissions are placed in a folder and not checked until the week is over, maximizing student effort. It also allows other teachers to offer the same reward, as it is not necessary to solve the puzzle yourself in offering the reward.

Questions to Ponder

Julianne Opperman [NEST '97]

NEST members are among the most proactive STEM teachers anywhere. These questions are for us and our colleagues.

1. Have I read the Framework for Science Education all the way through?
2. Have I read the Common Core section that discusses reading and writing in Science and Social Studies?
3. Have I had a conversation with a colleague in my school about a specific aspect of the Framework?
4. Have I had a conversation with an elementary teacher in my district about STEM?
5. Was he or she a kindergarten teacher or a primary level teacher?
6. Have I read any of the Next Generation Science Standards?
7. Have I followed one content, practice or cross cutting concept from Kindergarten through twelfth grade?
8. Am I going to see if an aspect of engineering practices fits into my current curriculum?
9. Am I going to talk to a writing teacher about how we can collaborate to teach scientific and technical writing?
10. Am I going to teach my students how to read primary research papers or how to read a textbook?

Educational Impediments

[This excerpt is from *The Paideia Proposal*, written by Mortimer J. Adler in 1982.]

The hopeful fact is that from the moment of birth children are capable of learning. They are born with the desire as well as the need to know. That desire—natural curiosity—can be nourished or it can be starved. The failure to nourish it as early as possible has dire consequences for the child's later schooling and adult life.

The individual's innate disposition to learn can be put to use in infancy and early childhood. It is then that neglect by parents or adverse circumstance maims or crushes this natural capacity. Preschool deprivation is the cause of backwardness or failure in school.

Schooling cannot do the job it should do equally well for all children if some are adequately prepared for school and some are not.

For the school to succeed in giving the same quality of basic education to all children, all must be prepared for it in roughly equal measure. Hence, at least one year—or better, two or three years—of preschool tutelage must be provided for those who do not get such preparation from favorable environments.

The idea behind the Head Start experiment was, indeed, a sound one. Preparation for schooling is not a dispensable accessory to the reform we are proposing. It is an essential ingredient, strongly recommended wherever it appears necessary and expedient.

A democratic society, defined as an ideal to be approximated, is one in which all, being equal in their humanity, enjoy equality in treatment. But in actuality a democratic society is limited in its ability to effect such equality. It can do only through the public agencies it is able to finance and over which it can exercise some control. Preschool tutelage should, therefore, be provided at public expense for those who need but cannot afford it.

The home is a private, not a public, institution. The inequality of homes produces inequalities of nurture that lead some to draw wrong conclusions about the abilities of children. Instead of seeing them as differing only in the degree to which they have a present or future capacity for learning, they divide them into those who are truly educable and those who are not. This division is then used to justify our not trying to give all the children the same quality of schooling. We keep all in school for the same number of years, but do not accord them equal treatment.

The sooner a democratic society intervenes to remedy the cultural inequality of homes and environments, the sooner it will succeed in fulfilling the democratic mandate of equal educational opportunities for all.

Without preparation for schooling, the chances of success in any attempted reform of the public school are greatly diminished. Without it, the country may even continue to believe the self-defeating doctrine that says not all children are educable and only some deserve the best quality of schooling we can afford.

The Cambrian Explosion

[These excerpts are from a review by Christopher J. Lowe of a book by the same title that appeared in the June 7, 2013, issue of *Science*.]

The Ediacaran and Cambrian periods witnessed a phase of morphological innovation in animal evolution unrivaled in metazoan history, yet the proximate causes of this body plan revolution remain decidedly murky. The grand puzzle of the Cambrian explosion surely must rank as one of the most important outstanding mysteries in evolutionary biology. Evidence of early representatives of all the major animal phyla first appear abruptly in the Cambrian (starting 542 million years ago). This spectacular morphological diversity contrasts strongly with Precambrian deposits, which have yielded a sparse fossil record with small, morphologically ambiguous trace fossils or the enigmatic but elegant creatures of the Ediacaran fauna. Following the Cambrian, despite a rich fossil record that documents impressive morphological diversification among animals, no new body parts have been revealed, leaving the Cambrian as the apparent crucible of metazoan body part innovation. Although it is only in the various Cambrian fossil assemblages that this exuberance of animal life first makes its appearance, molecular clock calculations estimate divergence times of the major metazoan lineages well before the Cambrian. That suggests a prolonged period of cryptic evolution in the Ediacaran not well represented in fossils, adding further intrigue to the puzzle.

The range of hypotheses proposed to explain the Cambrian explosion is diverse and broad as the fossils they seek to explain. Researchers from a wide range of sciences (including geology, ecology, developmental biology, and genomics) have all made substantial contributions toward unraveling the causes of this key puzzle of animal evolution. Yet in most cases, their findings have been considered independent of one another….

Readers of *The Cambrian Explosion* will likely have either little background or some expertise in one of the disciplines covered. Falling into the latter camp, I have largely considered causes of the Cambrian explosion from the perspective of molecular genetics and genomics. Erwin and Valentine illuminate clear links between seemingly disparate disciplines, and they make a compelling case that substantial progress toward understanding the origins of animal diversity will not be achieved through adding isolated gains in individual fields. It is futile to hope to explain such a major evolutionary event without embracing an interdisciplinary approach.

Leonard Ornstein

Avi Ornstein [NEST '89]

Leonard Ornstein, Director of Mount Sinai Hospital's Cell Research Laboratory from 1954, Professor of Pathology at Mount Sinai School of Medicine, New York, from 1966 to 1992, and Emeritus Professor since his retirement in 1992, has died at the age of 87. Born in 1926, Dr. Ornstein had a long and distinguished career in cell biology and cytochemistry, with technical specialties in flow cytometry, electrophoresis, bioengineering, biophysics, electro-optics, optical and electron microscopy, biological instrumentation, and automated medical diagnosis. He also researched and wrote about information theory and meaning, pattern recognition and artificial neural networks, epistemology, agricultural irrigation and global warming.

Dr. Ornstein was involved in a number of groundbreaking studies. He is most well-known for pioneering, along with colleague B.J. Davis, a technique called polyacrylamide gel electrophoresis in 1964, used for the analysis of proteins and nucleic acids. He also developed the first high-resolution methods for certain enzymes, and produced the first electron-microscopic images of the internal structure of mitochondria, cilia and flagella, pores of nuclear membranes, and other organelles. His doctoral work analyzed ways to test the hypothesis that haploid cells had half the DNA of diploid cells.

Leonard Ornstein invented new techniques for blood cell analysis used in hospital diagnostic machinery. He also invented devices for agricultural irrigation, and worked with colleagues to invent materials and improved processes for obtaining frozen tissue sections during surgery. He held 26 patents in the fields of histochemistry, bioengineering and agricultural irrigation. Among other honors, Dr. Ornstein was recognized in London, in 1986, when he was presented with the Founder's Award by the Electrophoresis Society, and again, in 1991, in New York, when he received the Van Slyke Award for Outstanding Contributions to the Science of Clinical Chemistry by the American Association for Clinical Chemistry, New York Metropolitan Section. He has been a Fellow of the American Association for the Advancement of Science since 1992.

Leonard Ornstein served in the U.S. Navy as a Hospital Corpsman during World War II. He earned his A.B. from Columbia College (1948), and his A.M. (1949) and Ph.D. (1957) from Columbia University, and taught and conducted research in Columbia University's Biology Department from 1949 to 1964. He joined Mt. Sinai Hospital in 1954, becoming a Professor of Pathology in the School of Medicine in 1966. During and after his tenure at Mount Sinai, he consulted for numerous companies on medical technology and instrumentation, including Technicon/Miles/Bayer/now Siemens Corporation.

The previous paragraphs are from the obituary statement of my father, who passed away last month, but I wish to add depth and give more meaning to the terms and ideas expressed therein. While earning his bachelor's degree in biology and master's degree in zoology at Columbia, he also took **all** the courses needed to major in chemistry, physics and engineering except for doing theses in those fields. He graduated with honors and did all of this in two and a half years. In addition, he actually had 29 patents.

"The Cell Research Laboratory" is a paper he wrote that was published in January 1957. The following is the opening paragraph, which identifies the work he was doing and would continue for over half a century.

> As our knowledge increases, there has been a growing conviction that a living organism is substantially more complicated than the biochemist's "bag of enzymes," and even the most elaborate of physical "machines". We now realize that hope of an *approach* to complete understanding of its behavior and function, normal and abnormal, can come only from combined structural and functional inquiries,—from the organismal level down,—and from the molecular level up.

Cytochemistry is the study of living cells, especially when studied microscopically, while cytometry generally refers to the group of biological methods used to measure the various conditions of cells. Histochemistry deals with using stains to identify the distribution of the chemical constituents of tissues. All of these are fields in which he made great advances. Epistemology is the study of knowledge and justified beliefs, which was an underlying factor in the way he perceived the world.

Electrophoresis uses an electric current to separate molecules according to their size and structure as they move through a fluid. Within five years, the joint papers that he and B.J. Davis wrote in 1964 on polyacrylamide gel electrophoresis were the fifth and fiftieth most cited scientific papers in the world, according to the Science Citation Index. Their analysis of proteins and nucleic acids is a fundamental concept in modern science. Electron microscopy opened up a detailed world of what happens within the cell. My father played a critical role in this advancement and, when I was in college, he was ranked of one of the three top scientists in that field in the U.S. He had developed the methacrylate embedding media that allowed electron microscopists to embed their specimens, which George Palade used for his work that led to receiving the 1974 Nobel Prize in Physiology and Medicine. In addition, my father developed the techniques used to analyze and diagnose the blood samples that are taken in a hospital or a doctor's office.

As the use of computers expanded in the latter half of the twentieth century, Leonard Ornstein investigated ways to enable a computer to process data and develop a degree of thinking. This is the artificial neural network noted in the obituary. A personal interest in bonsais in the 1980s led to the invention of the Irristat, a self-regulating watering device that can be used in both home plant care and agriculture. It was another application of his expertise in polyacrylamide gels. This, in turn, led to his involvement in dealing with global warming, working out a feasible method of addressing this critical problem.

Leonard Ornstein has a fundamental and lasting impact on scientific research and the advancement in a wide range of fields. While his contributions are valuable to society, he will still be sorely missed.

Where Are They Now?

Nick Serrembana, NEST Student Award recipient for 2012 under **Avi Ornstein [NEST '89]** at Classical Magnet School in Hartford, CT, received first place in the city's 2013 Science Fair.

Judging Science Fairs

Avi Ornstein [NEST '89]

Science fairs can give students a chance to do true experimentation. It can also give them a first-hand taste of what actual science is like. In school, most "experiments" are actually scientific exercises. The students are carrying out a set procedure that is expected to lead to specific results. True experimentation involves searching the unknown to expand our understanding of the world. Results are gathered and they are then studied to see if any meaningful conclusions can be drawn from them.

When I took biology, almost half a century ago, I did a science fair project investigating symbiosis in green hydra. Whether the hydra and algae had an actual symbiotic relation was unknown at that time, and that sparked my curiosity. My month of research resulted in a supportive conclusion, though it by no means resolved the question. More importantly, it gave me a clearer image of what scientific experimentation actually is.

Several fellow alumni of MIT serve as judges in science fairs. Henry Link, Class of 1967, has been a judge for five years. When I asked him why he chose to volunteer for this role, he responded: "I did it so that when I interviewed the students, I would not only evaluate their project, but also encourage them to consider a CAREER in the STEM fields rather than just a one-time project." Jack Solomon, Class of 1963, is amazed at the projects they review. "There are many schools that have no participation in Science Fairs," he stated. "I would urge teachers from these schools to encourage their students to look for outside mentors to help them. In that way, it would not be too burdensome on the teacher and his time and yet the student could work on a project."

The criteria used in judging science fairs vary. Different rubrics are used at different fairs. Not all include interviews. Some are far more specific than others. While some may be better than others in the system of judging, that is not the critical issue. Independent of the judging system that has been created, some judges will be more liberal while others are more critical. The score given to the same entry can vary greatly from one judge to another, but the order of ranking of the entries judged is usually similar. Nonetheless, the difference in judging can skew the results. Sometimes winners have poorer entries than losers. The final results depend on who judges whom.

The problem is that some poor entries happen to only be graded by liberal judges while some great entries are only graded by critical judges. The solution is that all equivalent entries—those that are competing with one another, whether according to age or subject—should be evaluated by the same set of judges. In this way, the existence of different 'scales' of judging will wash out when the scores are averaged. Apples will be compared to apples and the results will be more meaningful. This may be more difficult to carry out, but it is well worth the time and effort.

A friend felt that the previous two paragraphs should not be included in this article. If students became aware of this dichotomy, he fears, they will be disillusioned from participating in science fairs. That may be true, but students are not the audience I feel needs to be addressed. This problem is real and should not be merely ignored. It may be very difficult to resolve this, as it frequently is not easy to find judges in the first place, let alone having enough to resolve this issue. Nonetheless, it is something that should be kept in mind whenever a science fair is being held. It is certainly far better trying to solve this problem rather than merely looking aside and making believe that it does not exist.

Teaching Is an Art

Avi Ornstein [NEST '89]

Teaching is an art, not a science. This opinion may at first sound skewed, considering that my degree is in biology and that I have been involved in science education for almost four decades. However, prior to this profession, I survived for a few years as an artist and have other members of my family who have also spent portions of their lives as artists. I therefore feel I have the personal experience to validly make such a statement.

Unlike science, art is qualitative rather than quantitative. You start with an image in your mind and you use the medium to bring it forth so others can sense it. The same is true for teaching. The education that is offered to students comes from within the teacher, adjusting and modifying as the student population changes and meeting the needs of individual students. It requires patience, concern, focus and insight. Knowing the content of the curriculum is not enough, as you need to know how to deliver it in a way that reaches the students, hopefully having an impact on how they use their minds and how they interact with one another.

There are those who feel that anyone can teach. They believe that, if the system is set up properly, anyone can stand before a classroom, following a set of directions, and the students will be educated. This is far from the truth. Similarly, the same minds think that the quality of teaching can be judged by how students perform on standardized tests. If you teach the material so that students can do well on these tests, it does not mean that they are well educated. Teaching to the test is actually in conflict with meaningful goals.

As Einstein said, "Imagination is more important than knowledge." Anyone can look up facts. The facts by themselves have little meaning. The students need to know how to understand and use that knowledge, and that is our role as teachers. Our responsibility is to teach students to think. This means that they know how to put ideas together and then use them. They must to be able to communicate, expressing their own views and understanding the opinions of others with an open mind. When confronted with problems, they must have ideas of what to do or at least where to go to get help. In short, our underlying goal is not to teach them facts, although they do need a foundation to succeed in any subject. We cannot say what each student will need in the future, so we our vision should be that they learn how to learn—and achieving that is an art.

Two Emails and the Road to MIT

Bob Kahn [NEST '13]

In the Spring of 2011, I had strong convictions that video games were an enormous waste of time, especially for young minds. Then, an email. "Turn your class into a game with 3D GameLab," read the subject. A pause. Unsure of what this would be like, I thought "maybe I could reach a few kids that I otherwise wouldn't reach." I clicked the mouse and signed up for the 3D GameLab online summer teacher camp. Summer camps often change lives; this one changed mine.

Immersed in the camp, I quickly realized the error of my ways, the value of video games and the importance of teaching students (and my own two children) how to use technology. The result: the birth of my World of Warcraft avatar, Irongoran; a middle school Minecraft Exploratory at Brentwood School; and a presentation at Minecon in Las Vegas. In addition, I created my own blog (www.middleschoolminecraft.com) and I began tweeting my posts. This last Spring, Scott Perloff, the Director of Educational Technology, organized the first STEAM Day at Brentwood School with me. To top it off, this fall I will teach our first middle school Robotics course.

After STEAM Day, Scott sent me an email that included a link to the MIT SEPT 2013. I never dreamed that the road I was on would lead to MIT. To have drunk from the MIT 'fire hose' will truly be one of the most treasured and inspirational experiences of my education as a teacher and of my life. Moreover, it's only made me thirstier. After twenty years of teaching science, I have found inspiration for the next twenty.

Underpaid Teachers

[This excerpt from a website of NEA Today was forwarded by **Kristen Record [NEST '11]**.]

The American public mostly believes teachers are underpaid, and the proportional spending on teacher salaries in the U.S. falls short of the same spending on teacher salaries in the other developed countries—reflecting different spending priorities.

Teacher salaries in U.S. secondary schools make up 55.3% of the total education expenditures, which is notably lower than the 62.8% average of OECD countries. Countries that devote a higher percentage of their education budgets to salaries include Canada (62.4%), France (59.5%), United Kingdom (57.1%), and Korea (56%). The proportion spent on teacher salaries in Finland (51.7%) was, however, slightly lower than in the U.S. A different picture emerges when comparisons are made between the U.S. and other OECD countries on the compensation of 'non-teacher' staff, including school administrators. At 26.1%, the U.S. spends a higher proportion than other developed countries on non-teacher salaries. Most OECD countries range between 12-18%, with a low of 8.6% in Korea.

Voluntary Service

Avi Ornstein [NEST '89]

Voluntary service is very important to me, on a variety of levels. I first got involved in it when I was in high school, pushing our school's National Honor Society to expand the component of service to the community. In college, I was very active in Alpha Phi Omega (APO), the national service fraternity. While I earned a degree in biology at MIT, several friends said that I was actually majoring in APO. During my last term, in addition to having a part-time job, I usually put in thirty to forty hours of voluntary service each week, while earning straight A's in my classes.

When I became a teacher, I extended this interest to running community service clubs in two different school systems over about fifteen years. However, I no longer do that, as students now must put in mandatory voluntary service hours to be able to graduate. I find that when it is required, voluntary becomes a misnomer, which runs against the values that should be instilled in our students.

A few weeks ago, I had an actual dream of the formation of a national organization of former college volunteers. It involved all types of organizations, and they were going to high schools and getting across the value of voluntary service, getting students to go beyond mandated minimum and then continue in college—and life. While the details of my dream were fuzzy, I woke up with a 'motto song' that I quickly jotted down so as not to forget:

In all our lives we learned to share.
We think that you should also care.

Rather than focusing on the need to help others to be able to graduate from school, we should focus on having students learn why helping others is important. It not only helps those that we are serving, it helps ourselves, giving us an inner peace and meaningful values. We gain a better perspective of the world and what it might be, rather than what it is. When I was in APO, we described our cardinal principles as "we developed leadership and friendship by doing service." Or, as Nelson Mandela said, "What counts in life is not the mere fact that we have lived. It is what difference we have made to the lives of others that will determine the significance of the life we lead."

Good Teachers

[This excerpt is from an editorial highlight in the February 2013 issue of *Phi Delta Kappan*.]

Good teachers are essential and need respect. There is no substitute for good teachers. The effect of good teachers extends beyond positive educational outcomes and can be linked to positive societal factors, such as lower levels of teenage pregnancy and a greater tendency to save for retirement. Creating the best teachers is about more than paying a good salary. The best-performing countries attract top talent, train teachers throughout their careers, and allow them freedom.

A Change in Perspective

[These excerpts are from a brief article by Klaus Schwab that appeared in *Fortune* on February 4, 2013. While it was focused on economics, these thoughts have applications to education.]

…the system should be strategic, not crisis-driven. Most of our energy is currently absorbed by reactive rather than proactive measures. Managing crises instead of thinking about the future leads to a defensive attitude. We must adapt to a changing world, not defend outdated models.

…a global system must continually demonstrate legitimacy. Today, this goes beyond mandates based on democratic principles; it includes clear objectives and concrete results. We undoubtedly have a delivery problem. And since promised actions are not fulfilled, we also have a trust deficit with governments, international organizations, and business.

An End to Waste?

[These excerpts are from an editorial by Janet G. Hering that appeared in the August 10, 2012 issue of *Science*.]

Even though waste is an inevitable accompaniment to all processes, contemplating an end to waste can force us to think about how we define, generate, and manage it. Two common definitions of waste are a substance or object that is discarded and the avoidable loss of a resource. The current waste management practices in industrialized countries are widely recognized to be unsustainable, yet it is clear that we are not changing our practices effectively or fast enough. What are the impediments and how can we overcome them?

Current waste management practices include the options of disposal, recovery, recycling, reuse, minimization, and prevention. Reuse begins to blur the definition of waste: If an unwanted by-product of one industry can be used as a feedstock for another, is it a waste or a resource? For example, food and crop was been identified as a valuable feedstock for biofuel production. And with improved extraction technologies, wastes generated by past mining activities can serve as a valuable source of mineral resources. More effort is needed to identify such potential opportunities, develop the technologies needed to extract them, and remove any regulatory or legal constraints to manipulation. Such efforts should target the sectors that generate the most waste….

Under current practices, many environmental costs of production, including waste generation, are externalized; that is, they are not incorporated into the cost of products. …But political processes, such as regulation, are generally necessary to achieve such goals. It is therefore critical to raise the awareness of waste as an important societal issue….

Public awareness will be crucial if waste management is to be addressed from the perspective of consumption as well as production. This is essential if a displacement of costs, either in place or in time, is not to be mistaken for a gain in efficiency….Thus, the question of waste also requires that we examine our patterns of production and consumption and adjust them to the inevitable limits of our planetary ecosystem.

> Your teacher didn't lie to you....He merely edited his information...so as not to force on the impressionable minds of children things their parents did not want them to hear. Education has ever been thus.
>
> — Piers Anthony
> *A Spell for Chameleon*

Climate Change

[These excerpts are from an editorial article by Bassam Z. Shakhashiri and Jerry A. Bell that appeared on page 9 of *Science* on April 5, 2013.]

Communicating the science of climate change provides one example where the scientific community must do more. Climate change affects everyone, so everyone should understand why the climate is changing and what it means for theme, their children, and generations to follow. Scientists are already members of groups that can facilitate this communication: neighborhoods, school boards, religious groups, service clubs, political organization, and so on. These groups present opportunities to engage in respectful conversations on climate change and on the policies and actions that individuals, communities, and nations might take to mitigate and adapt to what is happening to our planet.

We know that the concentrations of greenhouse gases in Earth's atmosphere are higher and increasing faster than at any time in the past 1 million years. The average temperature of Earth is increasing, ice is melting, oceans are acidifying, and extreme weather events are more frequent. Human activities, principally the combustion of fossil fuels, are a major source of greenhouse gases and a major driver of climate change. To share this knowledge with the public and be credible as a "scientist-citizen," a scientist must acquire a good grasp of the science of climate change….

F. Sherwood Rowland…spoke to all scientist-citizens when he asked: "Isn't it the responsibility of scientists, if you believe that you have found something that can affect the environment, isn't it your responsibility to do something about it, enough so that action actually takes place?...If not us, who? If not now, when?"

We pose these same questions and ask you to join the conversations now.

> Science is curiosity, discovering things and asking why....Indeed, science is the opposite of knowledge. Science asks the why and how questions and therefore is the process of questioning, not the acquisition of information.
>
> — Victor Weisskopf
> The Privilege of Being a Physicist

Studying Misconceptions

[Kristine B. Quinlan and Andrew P. Dicks of the University of the Toronto Department of Chemistry wrote "Ten First-Year Chemistry Student Studying Misconceptions," which appeared in the April 2013 issue of *Chem 13 News*. While this focuses on entry-level college courses, many of the ideas apply equally to high school students.]

1. *"It is important that I study as much and in the same way as my friends."*
   …students often feel pressure to study as much and in the same way as their peers. However, different students have different backgrounds and different learning styles….Each student needs to figure out what works best for him or her. For instance, some students find reading the textbook intensively increases their understanding while others might find that they cannot absorb the material in that way and that their time is better spent reviewing the lecture notes, with the textbooks used to clarify certain points. In chemistry, all students will need to spend a significant fraction of their study time doing problems as this is an integral part of all physical science courses.
2. *"I don't need to prepare for lectures."*
   As the saying goes: "fail to prepare to fail." Does this mean that students should prepare slavishly before each chemistry lecture? No (there isn't time!), but a little studying goes a long way towards receiving maximum benefit from class hours….A review of new chapter material before it is studied in class (to become familiar with new terminology, equations, principles, etc.) has huge impact on understanding during lecture. A useful tip is to read the end-of-chapter summary as a starting point to get an overview of the major concepts.
3. *"I don't need to make any notes in class… it's much better is I just listen."*
   Going to lecture is not like going to the local movie theatre….some students claim they are "unable to write and listen at the same time", and watch lectures as if viewing television. This is the same generation of multi-taskers who simultaneously use Facebook, Skype and listen to music via ITunes! Fundamentally, making notes in class lays the foundation for further study outside the classroom. Failing to do it severely impacts the in-class and subsequent out-of-class learning experiences.
4. *"Lectures cover everything I need to know for test purposes."*
   Attending classes and merely memorizing their content is a very ineffective study technique….How do students become proficient at problem-solving? By initially being shown worked examples in lecture, and then by "getting their hands dirty"—studying in groups, talking about foreign concepts, referring to the assigned textbook and working through new problems.
5. *"I have to record what my professor says… there's plenty of time later to go through them and make detailed notes."*
   There is little doubt that listening to lecture recordings can be beneficial, but doing this should not be perceived as a substitute for making good notes whilst in lecture. Listening to an instructor talking whilst riding the subway home at night is not the same as being engaged with the material in class. In addition, it can take a LOT of time to sit down and transcribe three hours of recorded material every week….
6. *"I should ask questions in class the minute I don't understand something."*
   Chemistry is a fundamentally challenging subject. It is highly unlikely that every student in every class will understand every new concept the first time it is formally presented. Whilst asking a lecture question is to be encouraged, one along the lines of "I don't understand what you just said" is not so helpful. When students look at subject material after class they will often get to grips with it quite quickly… and think of good questions to ask in the next lecture.
7. *"There is no point asking for help in a large class."*
   …many resources are available and should be taken advantage of….help is available to every student willing to take advantage of the available resources.
8. *"If I understand the answers in the solutions manual, I am ready for the term test."*
   Improper use of a textbook solutions manual can give a false sense of security in terms of preparedness for term tests. Chemistry is a problem-solving discipline and involves both practice and a thorough understanding of concepts. Reading through answers in the solutions manual and being able to follow the steps does not give the required practice or understanding, which can lead to students thinking they know the material better than they actually do....Ultimately, students need to learn the concepts behind the problems, not the mechanics of a particular problem.
9. *"As long as I can do some of the assigned tutorial problems, I am ready for the term test."*
   In chemistry classes, a range of questions are usually assigned to help students learn the concepts and hone their problem-solving skills. While it is tempting to skip the more challenging problems and focus on the more straightforward ones, it is important to be proficient in all of the problems….
10. *"The term tests are harder than the assigned problems."*
    Every year student evaluations show that students believe the assigned problems are easier than the term test problems, even if very challenging problems are covered in the tutorial questions. Two things lead to this perception. The first is that students are, understandably, nervous during term tests….The second is that students no longer have the resources that they used while doing the practice problems, including the solutions manual, friends, teaching assistants, lecture notes and textbook. To be prepared for tests, it is important to try some problems under controlled conditions—both to assess preparedness and to gain the confidence needed….

The Origin of the Earth

[This brief article by Harold C. Urey appeared in the October 1952 issue of *Scientific American*.]

Aristarchus of the Aegean island of Samos first suggested that the earth and the other planets moved about the sun—an idea that was rejected by astronomers until Copernicus proposed it again 2,000 years later. The Greeks knew the shape and the approximate size of the earth, and the cause of eclipses of the sun. After Copernicus, the Danish astronomer Tycho Brahe watched the motions of the planet Mars from the observatory on the Baltic island of Hveen; as a result Johannes Kepler was able to show that Mars and the earth and the other planets moved in ellipses about the sun. Then the great Isaac Newton proposed his universal law of gravitation and laws of motion, and from there it was possible to derive an exact description of the entire solar system. This occupied the minds of some of the greatest scientists and mathematicians in the centuries that followed.

Unfortunately it is a far more difficult problem to describe the origins of the solar system than the motion of its parts. Indeed, what was the process by which the earth and other planets were formed? None of us was there at the time, and any suggestions that I may make can hardly be considered as certainly true. The most that can be done is to outline a possible course of events which does not contradict physical laws and observed facts.

A vast cloud of dust and gas in an empty region of our galaxy was compressed by starlight. Later gravitational forces accelerated the accumulation process. In some way which is not yet clear the sun was formed, and produced light and heat much as it does today. Around the sun wheeled a cloud of dust and gas which broke up into turbulent eddies and formed protoplanets, one for each of the planets and probably one for each of the large asteroids between Mars and Jupiter. At this stage in the process the accumulation of large planetesimals took place through the condensation of water and ammonia. Among these was a rather large planetesimal which made up the main body of the moon; there was also a large one that eventually formed the earth. The temperature of the planetesimals at first was low, but later rose high enough to melt iron. In the low-temperature stage water accumulated in these objects, and at the high-temperature stage carbon was captured as graphite and iron carbide. Now the gases escaped, and the planetesimals combined by collision.

So, perhaps, the earth was formed!

But what has happened since then? Many things, of course, among them the evolution of the earth's atmosphere. At the time of its completion as a solid body, the earth very likely had an atmosphere of water vapor, nitrogen, methane, some hydrogen and small amounts of other gases. J.H.J. Poole of the University of Dublin has made the fundamental suggestion that the escape of hydrogen from the earth led to the oxidizing atmosphere. The hydrogen of methane (CH_4) and ammonia (NH_3) might slowly have escaped, leaving nitrogen, carbon dioxide, water and free oxygen. I believe this took place, but many other molecules containing hydrogen, carbon, nitrogen and oxygen must have appeared before free oxygen. Finally life evolved, and photosynthesis, that basic process by which plants convert carbon dioxide and water into foodstuffs and oxygen. Then began the development of the oxidizing atmosphere as we know it today. And the physical and chemical evolution of the earth and its atmosphere is continuing even now.

The Trouble with Testing Mania

[These excerpts are from an editorial that appeared in *The New York Times* on July 13, 2013.]

Testing did spur some progress in student performance. But it has become clear to us over time that testing was being overemphasized—and misused—in schools that were substituting test preparation for instruction. Even though test-driven reforms were helpful in the beginning, it is now clear that they will never bring this country's schools up to par with those of the high-performing nations that have left us far behind in math, science and even literacy instruction.

Congress required the states to give annual math and reading tests in grades three through eight (and once in high school) as a way of ensuring that students were making progress and that minority children were being fairly educated. Schools that did not meet performance targets for two years were labeled as needing improvement and subjected to sanctions. Fearing that they would be labeled poor performers, schools and districts—especially in low-income areas—rolled out a relentless series of "diagnostic" tests that were actually practice rounds for the high-stakes exams to come.

That the real tests were weak, and did not gauge the skills students needed to succeed, made matters worse. Unfortunately, most states did not invest in rigorous, high-quality exams with open-ended essay questions that test reasoning skill. Rather, they opted for cheap, multiple-choice tests of marginal value. While practically making exams the center of the educational mission, the country underinvested in curriculum development and teacher training, overlooking the approaches that other nations use to help teachers get constantly better.

The government went further in the testing direction through its competitive grant program, known as Race to the Top, and a waiver program related to No Child Left Behind, both of which pushed the states to create teacher evaluation systems that take student test data into account. Test scores should figure in evaluations, but the measures have to be fair, properly calibrated and statistically valid—all of which means that these evaluation systems cannot be rushed into service before they are ready.

Foreign nations with the highest-performing school systems did not build them this way. In fact, none of the top-performing nations have opted for a regime of grade-by-grade standardized tests. Instead, they typically have gateway exams that determine, for example, if high school students have met their standards. These countries typically have strong, national curriculums. Perhaps most important, they set a high bar for entry into the teaching profession and make sure that the institutions that train teachers do it exceedingly well.

…Congress could ease some of the test mania by rethinking the way schools are evaluated under No Child Left Behind. Test scores are important to that process, but modest weight should be given to a few other indicators, like advanced courses, promotion rates, college-going rates and so on. Similarly, the states that have allowed the districts to choke schools with the diagnostic tests and data collection could reverse that trend so that schools have perhaps one or two higher-quality tests per year. In other words, the country needs to reconsider its obsession with testing, which can make education worse, not better.

Spatial Skills and Creativity

[This excerpt is from an editorial that appeared in *The New York Times* on July 15, 2013.]

…The study looked at the professional success of people who, as 13-year-olds, had taken both the SAT, because they had been flagged as particularly gifted, as well as the Differential Aptitude Test. That exam measures spatial relations skills, the ability to visualize and manipulate two-and three-dimensional objects. While math and verbal scores proved to be an accurate predictor of the students' later accomplishments, adding spatial ability scores significantly increased the accuracy.

The researchers, from Vanderbilt University in Nashville, said their findings make a strong case for rewriting standardized tests like the SAT and ACT to focus more on spatial ability, to help identify children who excel in this area and foster their talents.

"Evidence has been mounting over several decades that spatial ability gives us something that we don't capture with traditional measures used in educational selection," said David Lubinski, the lead author of the study and a psychologist at Vanderbilt. "We could be losing some modern-day Edisons and Fords."

Following up on a study from the 1970s, Dr. Lubinski and his colleagues tracked the professional progress of 563 students who had scored in the top 0.5 percent on the SAT 30 years ago, when they were 13. At the time, the students had also taken the Differential Aptitude Test.

Years later, the children who had scored exceptionally high on the SAT also tended to be high achievers—not surprisingly—measured in terms of the scholarly papers they had published and patents that they held. But there was an even higher correlation with success among those who had also scored highest on the spatial relations test, which the researchers judged to be a critical diagnostic for achievement in technology, engineering, math and science.

Cognitive psychologists have long suspected that spatial ability—sometimes referred to as the "orphan ability" for its tendency to go undetected—is key to success in technical fields. Earlier studies have shown that students with a high spatial aptitude are not only overrepresented in those fields, but may receive little guidance in high school and underachieve as a result. (Note to parents: Legos and chemistry sets are considered good gifts for the spatial relations set.)

The correlation has "been suspected, but not as well researched" as the predictive power of math skills, said David Geary, a psychologist at the University of Missouri, who was not involved in the study, which was funded by the John Templeton Foundation. The new research is significant, he said, for showing that "high levels of performance in STEM fields"—science, technology, engineering and math—"are not simply related to math abilities."

Testing spatial aptitude is not particularly difficult, Dr. Geary added, but is simply not part of standardized testing because it is considered a cognitive function—the realm of I.Q. and intelligence tests—and is not typically a skill taught in school.

Universal Laws of Complexity

[This excerpt is from a commentary by Geoffrey West entitled "Wisdom in Numbers" that appeared on page 14 in the May 2013 issue of *Scientific American*.]

The digital revolution is driving much of the increasing complexity and pace of life we are now seeing, but this technology also presents an opportunity. The ubiquity of cell phones and electronic transactions, the increasing use of personal medical probes, and the concept of the electronically wired "smart city" are already providing us with enormous amounts of data. With new computational tools and techniques to digest vast, interrelated databases, researchers and practitioners in science, technology, business and government have begun to bring large-scale simulations and models to bear on questions formerly out of reach of quantitative analysis, such as how cooperation emerges in society, what conditions promote innovation, and how conflicts spread and grow.

The trouble is, we don't have a unified, conceptual framework for addressing questions of complexity. We don't know what kind of data we need, nor how much, or what critical questions we should be asking. "Big data" without a "big theory" to go with it loses some of its potency and usefulness, potentially generating new unintended consequences.

When the industrial age focused society's attention on energy in its many manifestations—steam, chemical, mechanical, and so on—the universal laws of thermodynamics came as a response. We now need to ask if our age can produce universal laws of complexity that integrate energy with information. What are the underlying principles that transcend the extraordinary diversity and historical contingency and interconnectivity of financial markets, populations, ecosystems, war and conflict, pandemics and cancer? An overarching predictive, mathematical framework for complex systems would, in principle, incorporate the dynamics and organization of *any* complex system in a quantitative, computable framework.

We will probably never make detailed predictions of complex systems, but coarse-grained descriptions that lead to quantitative predictions for essential features are within our grasp. We won't predict when the next financial crash will occur, but we ought to be able to assign a probability of one occurring in the next few years. The field is in the midst of a broad synthesis of scientific disciplines, helping reverse the trend toward fragmentation and specialization, and is groping toward a more unified, holistic framework for tackling society's big questions. The future of the human enterprise may well depend on it.

Modern Theories of Electricity and Matter

[This brief article by Marie Curie appeared in the June 1908 issue of *Scientific American*.]

When one reviews the progress made in the department of physics within the last ten years, he is struck by the change which has taken place in the fundamental ideas concerning the nature of electricity and matter. The change has been brought about in part by researches on the electric conductivity of gas, and in part by the discovery and study of the phenomena of radioactivity. It is, I believe, far from being finished, and we well may be sanguine of future developments. One point which appears today to be definitely settled is a view of atomic structure of electricity, which goes to confirm and complete the idea that we have long held regarding the atomic structure of matter, which constitutes the basis of chemical theories.

At the same time that the existence of electric atoms, indivisible by our present means of research, appears to be established with certainty, the important properties of these atoms are also shown. The atoms of negative electricity, which we call electrons, are found to exist in a free state, independent of all material atoms, and not having any properties in common with them. In this state they possess certain dimensions in space, and are endowed with a certain inertia, which has suggested the idea of attributing to them a corresponding mass.

Experiments have shown that their dimensions are very small compared with those of material molecules, and that their mass is only a small fraction, not exceeding one one-thousandth of the mass of an atom of hydrogen. They show also that if these atoms can exist isolated, they may also exist in all ordinary matter, and may be in certain cases emitted by a substance such as a metal without its properties being changed in a manner appreciable to us.

If, then, we consider the electrons as a form of matter, we are led to put the division of them beyond atoms and to admit the existence of a kind of extremely small particles, able to enter into the composition of atoms, but not necessarily by their departure involving atomic destruction. Looking at it in this light, we are led to consider every atom as a complicated structure, and this supposition is rendered probable by the complexity of the emission spectra which characterize the different atoms. We have thus a conception sufficiently exact of the atoms of negative electricity.

It is not the same for positive electricity, for a great dissimilarity appears to exist between the two electricities. Positive electricity appears always to be found in connection with material atoms, and we have no reason, thus far, to believe that they can be separated. Our knowledge relative to matter is also increased by an important fact. A new property of matter has been discovered which has received the name of radioactivity. Radioactivity is the property which the atoms of certain substances possess of shooting off particles, some of which have a mass comparable to that of the atoms themselves, while the others are the electrons. This property, which uranium and thorium possess in a slight degree, has led to the discovery of a new chemical element, radium, whose radioactivity is very great. Among the particles expelled by radium are some which are ejected with great velocity, and their expulsion is accompanied with a considerable evolution of heat. A radioactive body constitutes then a source of energy.

According to the theory which best accounts for the phenomena of radioactivity, a certain proportion of the atoms of a radioactive body is transformed in a given time, with the production of atoms of less atomic weight, and in some cases with the expulsion of electrons. This is a theory of the transmutation of elements, but differs from the dreams of the alchemists in that we declare ourselves, for the present at least, unable to induce or influence the transmutation. Certain facts go to show that radioactivity appertains in a slight degree to all kinds of matter. It may be, therefore, that matter is far from being as unchangeable or inert as it was formerly thought and is, on the contrary, in continual transformation, although this transformation escapes our notice by its relative slowness. The conception of the existence of atoms of electricity which is thus brought before us plays an essential part in modern theories of electricity.

Image of Teachers

[This extract is from *The Limpopo Academy of Private Detection*, a detective story by Alexander McCall Smith set in Botswana.]

…Teachers seemed a different breed these days, more like everybody else; when she had been a pupil…the teacher had been a figure of authority in the village. People respected teachers and listened to what they had to say. She remembered walking with her late father on the road to Pilane when a cart had gone past, a donkey cart, and there had been a man sitting on the back holding a case of some sort and her father had raised his hat as the man passed. She had asked why he had done this, and he had replied that the man was a teacher and he would always raise his hat to a teacher. She did not think that happened today.

Science in Europe

[These excerpts are from an editorial by Maire Geoghegan-Quinn that appeared in the June 29, 2012, issue of *Science*. She is the European Commissioner for Research, Innovation and Science.]

Science is a necessity, not a luxury. The world is facing challenges on a scale not encountered before, including climate change, geopolitical upheaval, and demographic shifts. This has made policy-making more complex than ever, and informed decisions require the best evidence-based knowledge and advice we can produce. Science is also the key to our economic recovery. In Europe, countries that have invested in research are weathering the recent crisis much better. Innovative companies are more resilient, continuing to attract customers with the best products and services. So investment in science is investment in competitiveness and jobs...

The challenge now is to make sure we bring everyone along for the ride. The European project is based on progress, and science means progress. But the old models of doing science from on high are obsolete. We have to collaborate more widely across countries and across disciplines to meet our current challenges. We have to explain better what science is doing and why, in language that non-scientists can understand. We need to encourage more children to study science, not just so they can participate in the knowledge economy, but because a basic understanding of science is essential for living in an ever more complex and technological world.

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