Volume 9, Issue 3 - 2010

THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Best Observatory Site on Earth

The quality of astronomical observations is affected by cloud cover, temperature, brightness of the sky, water vapour, wind speed, and atmospheric turbulence. Researchers have identified a location known simply as Ridge A, 4,053 m high on the Antarctic Plateau, as the best observatory site on Earth. It is not the highest point on the Plateau, which is called Dome A, but is 150 km away along a flat ridge and no human being is thought to have yet been there.

Described as the coldest, calmest, driest place on Earth, Ridge A has an average winter temperature of -70°C and very little atmospheric turbulence (which causes stars to twinkle) and the water content of the entire atmosphere there is sometimes less than the thickness of a human hair. The astronomical images taken at Ridge A should be at least three times sharper than those taken at the best sites presently being used by astronomers, thus making a modestly-sized telescope there as effective as the largest telescopes anywhere else on Earth.

Source: Coldest, driest, calmest place on Earth. (2010). *Journal of College Science Teaching*, *39*(3), 8.

Teaching Ideas

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

Data Collection Using an Audience Response System

An audience response system (i.e., “clickers”) can be used for real-time data collection during one or more laboratory sessions, thus allowing students to readily combine data and perform statistical analyses on larger data sets. The student-paced assessment mode of an audience response system having this feature is used to collect the data. Questions about the data can be embedded throughout an activity, and the data displayed in a spreadsheet.

Source: Hunter, A., Rulfs, J., Caron, J. M., & Buckholt, M. A. (2010). Using a classroom response system for real-time data display and analysis in introductory biology labs. *Journal of College Science Teaching*, *40*(2), 19-25.

The Blog Assignment

A blog is an online conversation comprising messages that respond to an initial comment, and a blog assignment provides students with the opportunity to accommodate their digital needs while engaging in higher-level thinking. Having chosen a topic that may vary from student to student, the blog assignment for each student has three parts:

1. *Research*. Each students researches a topic using internet search engines, with the teacher possibly providing basic website guidelines (e.g., sites with .edu or .gov in their domain names may provide useful, initial factual information). Students will need to evaluate their search results for accuracy, bias, and currency.
2. *Report*. Students synthesize their findings and report their understanding in the form of individual blogs. The following exemplify free blog tools that are available:
   - Blogger (www.blogger.com/start)
   - LiveJournal (www.livejournal.com)
   - Thoughts.com (www.thoughts.com/free-blog)
   - WordPress (http://wordpress.com)

   Setting up a class blog requires an email address (e.g., that of the teacher) for registration and requires very little teacher preparation. Each blog will contain a mix of facts, references, and student opinion and will vary in format from student to student. The blogs are accessible to only members of the class and can be monitored by the teacher.
3. *Respond*. Students read the blogs of other students (e.g., all blogs, or at least five, say) and initiate a conversation by responding (e.g., each student asks at least three questions and provides at least five comments in the form of opinions or statements of fact). Students build understanding by evaluating the work of others.

The following are sample criteria for a rubric that assesses the student blogs: Amount of Information (e.g., all requirements met), Quality of Information (e.g., information relates to the chosen topic), Sources (e.g., references are provided using the required style), and Research (e.g., sources successfully evaluated and reliable sources selected).

Source: Baynard, L. (2010). Literacy for the digital generation: Enabling students to develop 21st-century skills through real-world chemistry. *Science Scope*, *34*(4), 32-37.

Distinguishing Organic and Inorganic Compounds

While over the last century the precise classification of organic and inorganic compounds has become of little or no importance to experimental scientists, understanding such a division is important in the school setting when introducing students to the vast subject of chemistry. The term *organic* was originally used by 18th- century chemists to describe substances obtained from living sources such as plants and animals. However, we now know that organic compounds can be synthesized from inorganic compounds without the need for any “vital force” from living matter. When burned, organic compounds produce carbon dioxide and water and typically char (the material remaining is carbon that has not burned because it cooled too quickly), whereas inorganic compounds do not char. Also, with prolonged, high-temperature heating, organic compounds burn away completely, leaving no ash, whereas inorganic compounds do not burn away completely. However, attempting to use such rules with precision is problematic, because there as so many exceptions. For example, oxalic acid is an organic compound that does not char on heating, cyanides are inorganic compounds that contain carbon, and tetracyanoethylene is an organic compound that does not contain hydrogen atoms.

A useful demonstration to distinguish organic and inorganic compounds is to simply strike a paper or wooden match and allow it to burn. The black residue is carbon, establishing that the material that has been burned is organic. However, the head contains a white inorganic compound residue, which is evidence that the match also contained inorganic compounds. Inorganic compounds that include phosphorus, magnesium, and potassium also burn, but leave a white residue rather than a black one.

In another demonstration, a cigarette lighter can be lit to demonstrate how shorter-chained carbon compounds burn completely, leaving no black residue. So, when repairing the mortar on the inside of a chimney, make sure an inorganic concrete patching material is used rather than an organic plumber's patching compound, as use of the combustible latter may produce flames in the chimney!

Source: Zaitsev, I. V. (2010). Striking a match: A short and effective classroom demonstration in introductory biology. *Journal of College Science Teaching*, *39*(5), 72-74.

Science Poetry

Reading and/or listening to poems composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Different Types of Energy

It comes from the underground
Near the Earth's core
It stands for Earth's-heat
And nothing more

It involves lava, rocks, and mantle
That is why it's not our enemy
It's all around us It's called
Geothermal energy

We take out its kinetic energy
To help us make light
And when we use it
Our world turns bright

It also makes heat
That keeps us warm
And helps us to live It's called
Hydro energy

Release it slow
It creates energy helping us
Release it too fast
It can blow up a bus
I call it
Nuclear energy

It comes from a plant
It comes from a tree
It is natural
Like you and me

It makes light
It makes heat
We call it
Biomass energy

They are our world
They are our light
They are our life

We use it to grow
So do plants
We put great panels on our roof
And when we get electricity we do a little dance

It's natural
It's free
And it's called
Solar energy

It flows through the air
It flows through the sky
And when you walk
It flows right by

It can change forms
It can change ways
But on hot days
I want it here to stay
It's called
Wind energy

It can change form
But cannot be destroyed
It's near you
It's by your side

They make us bright

We created them
To help us live
And they have done their duty
And for what they give

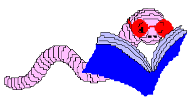
We are so grateful
We have them around
They are our types of energy
They make us proud

Jessica Morris, 11 years
Australia

Gravity

If gravity were turned around
We'd all fall up instead of down.
If I fell up I'd laugh out loud
Bumping my head into a cloud.
Planes would need more sky to share
For cars would soar into the air.
I probably would never cry
If I slipped and fell up in the sky.
But how would we stay on the ground
If gravity was turned around?

Ji Soo, 13 years
Vietnam



Research in Brief

Research findings from key articles in reviewed publications

Computer Supported Versus Real Laboratory Inquiry Learning Environment for Learning About Direct Current Electricity

Baser and Durums (2010) compared the changes in pre-service elementary school teachers' conceptual understanding about direct current electricity in virtual (computer simulations) and real laboratory environments. After completing the 3-week physics-by-inquiry based treatments, the results showed no difference between the two groups. The complete paper is freely available online.

Reference

Baser, M., & Durmus, S. (2010. The effectiveness of computer supported versus real laboratory inquiry learning environments on the understanding of direct current electricity among pre-service elementary school teachers. *Eurasia Journal of Mathematics, Science & Technology Education*, *6*(1), 47-61. Available from http://www.ejmste.com/v6n1/EURASIA_v6n1_Baser.pdf .

Use of Creative Drama

Cokadar and Yilmaz (2010) studied the effect of creative drama-based instruction on 45 seventh-grade Turkish students. Two classes, the experimental and control, taught by the same teacher studied ecology and matter cycles for 8 class hours over a 3-week period.

An ecological concept achievement test and a science attitude test were administered before and after the treatment. The treatment resulted in a statistically significant higher mean score on achievement of the ecology concepts, as well as higher median score for the attitudes toward science, for the experimental group compared with the control group that experienced traditional instruction.

Reference

Cokadar, H., & Yilmaz, G. C. (2010). Teaching ecosystems and matter cycles with creative drama activities. *Journal of Science Education and Technology*, *19*, 80-89.

Preferred Science Teaching Methods

While students find science relevant to society, they do not find school science interesting. Juuti, Lavonen, Uitto, Byman, and Meisalo (2010) surveyed 3,626 Finnish Grade 9 students' to determine how often particular teaching methods are used in chemistry and physics classes and their preferences for how they would like to study science (i.e., how often they would like to see various teaching methods used).

Boys seemed to be more satisfied than girls with current and traditional science teaching methods like direct teaching, solving basic problems, reading textbooks, and practical work. The authors suggest that the following can impact positively on students' feelings in the science classroom:

- Less teacher presentation of content on the blackboard;
- Less reading of textbooks;
- More out-of-school connections (e.g., visits, visitors, and use of newspapers and magazines);
- More discussions (for especially girls);
- For students who are interested in school science or who think that school science is relevant in everyday life, more group projects and creative activities such as brainstorming and project work.

Reference

Juuti, K., Lavonen, J., Uitto, A., Byman, R., & Meisalo, V. (2010). Science teaching methods preferred by Grade 9 students in Finland. *International Journal of Science and Mathematics Education*, *8*, 611-632.

Understanding Electric Circuits

In an investigation that involved a total of 50 elementary students, Jaakkola, Nurmi, and Veermans (2011) compared the learning outcomes of students who used a simulation alone to study electric circuits with outcomes of those who used a combined simulation/real circuit approach, and also explored how learning outcomes in these environments were mediated by implicit (only procedural guidance) and explicit (more structure and guidance for the discovery process) instruction. For students using simulation alone, explicit instruction enhanced learning considerably whereas implicit instruction was insufficient to promote conceptual understanding.

Surprisingly, for students who used the combined approach, explicit instruction did not seem to improve the understanding of electric circuits very much more than implicit instruction did. In fact, the explicit instruction slowed down the inquiry process substantially in the combined environment. However, outcomes in the simulation environment, even when explicit instruction was used, were not as high as those in the combined environment.

Reference

Jaakkola, T., Nurmi, S., & Veermans, K. (2011). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching*, *48*, 71-93.

A Correlative Study of CD-ROM Picture Books in Classrooms and School Children's Formation of Descriptive Concepts

By: Chow-Chin Lu, National Taipei University of Education, Taiwan, Republic of China (luchowch@tea.ntue.edu.tw), Yueh-Yun Chen, Taipei County Sioushan Elementary School, Taiwan, Republic of China (chen7329@gmail.com), and Chen-Wei Chen, Taipei County Jian Elementary School, Taiwan, Republic of China (awk.chen@gmail.com)

Lu, Chen, and Chen (2011) is a study about The General Guidelines of Nature and Technology curriculum in Taiwan (Ministry of Education, 2004), combined with story CD-ROM picture books and a discussion of fourth-grade students' descriptive concepts of insects' physical characteristics, behaviors, and life cycles. We analyzed the teaching materials for the unit Campus Insects, identified the target concepts to be learned and developed, emphasized story lines and images to present these descriptive concepts about insects that attracted students' attention, and composed three CD-ROM picture books (Xiao-Hua Looking for Relatives, Water Pool Pageant, and Intelligence 007 Ants) that employed forest roads, ponds, and a farm environment as authentic habitats for the target insects. The picture books utilized descriptive dialogue, images, video, informational text, animation, nature sounds, music, and other components.

The CD-ROM picture books were assessed using expert judgments of the CD-ROM picture books and the learning effectiveness of the books with elementary students. Four multimedia and biology university professors and 7 experienced primary school science teachers regarded as being good to very good practitioners believed that the use of the CD-ROM picture books was an effective teaching approach. In a quasi-experimental approach, students were randomly assigned to two groups (129 fourth-grade students in each group); a comparison group and a treatment group. The RCIC (Reading Comprehension Tests of Insect Curriculum) and OIDC (Open Questionnaire of Insect Descriptive Concepts) were used to evaluate the learning effectiveness of the three CD-ROM picture books.

A comparison of the pretest average RCIC scores on the total instrument, scientific terms, and scientific descriptive concepts for the two groups revealed non-significant differences, but the posttest scores revealed significant differences favoring the treatment group, so it appears that the CD-ROM experience helped the treatment group overcome a slight reading comprehension disadvantage at the beginning and develop significant better comprehension of the scientific articles. By comparing the two groups' OIDC answers, we found the distributions of descriptive concepts in all three general areas for the treatment group were mainly in the two highest levels (middle and high) whereas those for the comparison group were in the two lowest levels (none and low). The students in the treatment group developed a better understanding of the relationships between overall structure and function of insects. The CD-ROM picture books with verbal descriptions, printed scientific terms (concept labels), and images appeared to produce better learning effects through visual–auditory stimulation. This instructional treatment not only enhanced students' learning of scientific conceptions and enhance their imagination, but also enhanced their reading of scientific articles to help them learn more effectively.

These CD-ROM picture books can (a) improve students' ability to observe critical characteristics and details, (b) improve their understanding of the definitions of scientific terms and meaning of the expressions, (c) increase the use of scientific terms in the description of a concept, and (d) strengthen their reading and understanding of scientific articles at the same time.

When science teachers use CD-ROM picture books in teaching, they need to be aware of segmenting the CD to match the specific students, intersperse questions, and lead students in discussions with each other after showing a section of stories in order to help students focus on the target descriptive concept. The designers of CD-ROM picture books should pay attention to the story and describe scientific knowledge fully in terms of the intended audience while providing an interesting but not overwhelming story plot and characters. Teacher guidance during discussion should encourage students to think and avoid producing incomplete or alternative concepts.

Multimedia resources can improve student learning. However, it is necessary to set up an effective and useful evaluation system that is used by persons with appropriate expertise (e.g., multimedia experts, university professors who teach entomology, and/or experienced primary school science teachers) to assess multimedia resources and make the evaluative results available to teachers, thus allowing a variety of teachers to facilitate the attainment of targeted learning outcomes by specific types of students.

References

Lu, C-C., Chen, Y-Y., & Chen, C-W. (2011). A correlative study of CD-ROM picture books in classrooms and school children's formation of descriptive concepts. *International Journal of Science and Mathematics Education*, *9*, 46-67.

Ministry of Education. (2004). *Standards for nine-year continuous curriculum at elementary and junior high level in Taiwan*. Taipei: Ministry of Education.

Readers' Forum

A Question for Science?

Simpson (2010) has categorized student research questions as observational (e.g., "for how long do darkling beetles live?"), experimental (e.g., "does the surface make a difference in the speed at which beetles move?"), and literature-based (i.e., questions that might be answered by researching what others have discovered and reported, such as "what is the natural habitat of darkling beetles?"). However, the author claims that the question "why do beetles flip over on their backs?" cannot be answered in science, writing in-text that "we also discover that some questions cannot be answered in science—largely those that ask why something wants to behave as it does" (p. 37). With this I must disagree, suggesting that this question does lend itself to a legitimate application of the scientific method that is in fact central to the way science is done and the way the field of science progresses.

The scientific method, also referred to as the hypothetico-deductive (HD) approach, comprises the steps of making a puzzling observation, asking a causal question, advancing a hypothesis, generating a prediction from the hypothesis, designing a test to check on the prediction, and comparing the results of the test with the prediction from the hypothesis to draw a conclusion. In short, science is about generating and testing alternative explanations for puzzling observations. For an elaboration of the scientific method, please see Eastwell (2010) and the references it contains. To elaborate in the case of animal behaviour exemplified by the question being considered here, “possible explanations are of two main types: proximate and ultimate. Proximate, or mechanistic, explanations refer to the immediate stimulus that leads to the behavior as well as the internal mechanisms that produce the behavior. Ultimate, or evolutionary, explanations refer to the adaptive benefits of the behavior and the evolutionary paths through which the behavior was acquired. To suggest, as this author has, that such questions lie beyond the scope of science is certainly tossing the baby out with the bath water!” (A. Lawson, personal communication, December 28, 2010).

With that said, though, science does have its limitations, with one being that there are certainly some questions that science cannot answer. I categorize questions as being scientific, socio-scientific (e.g., “is abortion acceptable?”), and non-scientific (e.g., “is there any purpose in me being here?” “why do we have animals?” “which is the best painting?” and “when is judgment day?”). While science can certainly inform decision-making on socioscientific questions, it cannot answer socioscientific questions completely, because answering such questions also requires considerations that are outside the province of science; social, political, and economic concerns, personal opinions, values, morals, and beliefs, for example. As another example, we do not turn to science alone to answer the question “is it alright to clone?”

When it comes to answering non-scientific questions, science can be of no help at all. For example, biology has nothing to say about why I am here, nor if there is any purpose at all. When science says that a species has adapted, say, it is describing the outcome of reproduction amid competition. Confusion arises when this statement about adaptation is incorrectly interpreted to mean that the species has made a conscious decision to adapt. Science describes phenomena but doesn’t attribute purpose or volition. However, I think the issue of what categories of questions may be regarded as being non-scientific is a very interesting one indeed, worthy of a dedicated piece, so I’m planning to offer this in a forthcoming issue of this journal.

References

Eastwell, P. H. (2010). The scientific method: Critical yet misunderstood. *The Science Education Review*, *9*, 8-12.
Simpson, P. (2010). Personalized inquiry. *Science and Children*, *48*(4), 36-39.

Peter Eastwell, Science Time Education, Queensland, Australia

Author's Response

I agree with Peter Eastwell that the question "why do beetles flip over on their backs" can be addressed by science, because science can investigate questions about behavioural responses to stimuli. So, the question I meant to outlaw from science is "why do beetles want to flip over on their backs?" Here there is a suggestion about beetles having feelings and a desire/intent to flip, and science cannot answer questions about the emotional responses of animals. My elementary methods students seem to want to get to the emotional responses of their organisms, which I would argue is not a part of science.

Patricia Simpson, St. Cloud State University, St. Cloud, Minnesota, USA

Headings in Scientific Reports

I have previously distinguished scientific investigations that seek to answer causal questions (e.g., “why does a basketball go flat when taken outside in winter?” and “what does a plant need to grow”) and investigations that address non-causal questions (e.g., “how many types of living organisms can be identified in our school grounds?” and “does cooking affect the vitamin C content of vegetables?) (Eastwell, 2010). Responding to a causal question requires the use of the scientific method (also referred to as the hypothetico-deductive approach) that comprises the steps of asking a causal question about a puzzling observation, advancing a hypothesis (i.e., a possible, or proposed, scientific explanation for what is observed), generating a prediction from the hypothesis based on the assumption that the hypothesis is correct, designing and conducting a test to check on the prediction, and drawing a conclusion as to whether the results of the test support or contradict the hypothesis. On the other hand, trying to answer a non-causal question (also called a descriptive investigation or study) does not demand the use of the scientific method, and in particular therefore does not demand the advancement of a hypothesis (a proposed explanation) for testing because the research question does not ask for anything to be explained.

It follows, then, that the structure of an investigative report involving a causal question should be different to a report that addresses a non-causal question, and the suggested core report headings shown in Table 1 demonstrate the key differences. Specifically, by reflecting the steps of the scientific method, a report on a causal question will feature a hypothesis and a conclusion, defined as a "statement or statements that summarize the extent to which a hypothesis or theory has been supported or contradicted by observed results” (Lawson, 2010, p. 260), whereas a report on a non-causal question will feature neither of these but rather have a summary of results instead of a conclusion.

Table 1
Different Core Headings for Investigative Reports That Address Different Types of Questions

Causal Question	Non-Causal Question
Question Hypothesis (including overview of prediction and test) Method Results Discussion and Conclusion	Question Method Results Discussion and Summary

Different reports will, of course, have different emphases, so the core report headings shown in Table 1, which are suitable for school science, should not be viewed as being in any way rigid. For example, in a report that contains many different kinds of results, Discussion and Summary of Results might be separate headings. In another case, Results and Discussion may be the more appropriate heading. Or, in a report that is brief and rather straightforward, a Discussion section may not even be needed.

While trying to answer a non-causal question does not involve the testing of a hypothesis, for clarity and completeness it may be worth noting that the report of such an effort may contain a link with a hypothesis. For example, the non-causal question may have arisen within a larger context and as a result of some causal consideration. Here, a hypothesis might feature in the introduction to the report of the non-causal study. Or, a hypothesis may very well be advanced in the discussion section of a non-causal report because the results of the investigation may constitute a puzzling question in need of an explanation, thereby suggesting the use of the scientific method for further research. Alternatively, the results of the investigation of a non-causal question may test an existing explanation.

A report of research at a more advanced level may contain sections that include the following: Abstract, Introduction, Research Question(s), Hypothesis(es) (including overview of prediction[s] and test[s]), Significance of the Study, Review of Literature, Materials, Method, Results, Analysis of Results, Discussion, Conclusion, Summary, and Implications of the Study (for teaching and/or for further research). At times, a combination of such sections, such as Results and Analysis, may be appropriate. Also, the clarity of a report may be enhanced by presenting one or more sections with subsections, as in the case of a Method section being divided into the subsections of Sample, Instruments, Treatment, and Data Analysis, for example. However, while a report may have an introduction, the use of Introduction as a report heading is not necessary because the introduction is identified by its position in the report, and this practice reflects APA writing style.

As defined in the foregoing, the term *conclusion* is used in a very specific way in science investigations compared to the way it is used in the literature more generally to mean to bring "to a satisfying and logical end" (Nordquist, 2011, ¶ 1). Taking Nordquist's suggestions for writing a conclusion, we see that a conclusion encompasses what those of us in science call a summary, a conclusion, significance of the study, and implications. I advocate the finer distinction I have outlined here, as it seems to better represent the nature of science, how it is done, and how the field progresses. In short, a report on an investigation of a causal question should contain a hypothesis and a conclusion, whereas a report on a non-causal question will feature a summary.

References

Nordquist, R. (2011). *About.com: Grammar and composition*. Retrieved December 2, 2010, from http://grammar.about.com/od/c/g/conclusterm.htm .

Eastwell, P. H. (2010). The scientific method: Critical yet misunderstood [Readers' Forum]. *The Science Education Review*, *9*, 8-12.

Lawson, A. E. (2010). How ''scientific'' is science education research? *Journal of Research in Science Teaching*, *47*, 257-275.

Peter Eastwell, Science Time Education, Queensland, Australia

The Hypothesis

How pleasing it was to see Page Keeley's (2010) recent article correctly differentiating a prediction and a hypothesis, an issue about which I have been campaigning for quite a period of time (e.g., Eastwell, 2002, 2010). However, I must query some other aspects of the content of this article.

First, consider "hypotheses and theories are like apples and oranges—they have different features and a different purpose" (Keeley, 2010, p. 25). I disagree. In accord with Keeley's writing, a hypothesis is a possible, or proposed, scientific explanation for the observed facts and laws. A theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena (e.g., spontaneous generation theory, biogenesis theory, and atomic-molecular theory) (Lawson, 2008, 2010). While a hypothesis attempts to explain a specific puzzling observation (or group of closely-related observations), a theory is more complex, more general, and more abstract. However, the bottom line is that both a hypothesis and a theory represent the same kind of scientific knowledge; namely, a proposed explanation. Indeed, the distinction between a hypothesis and a theory can be somewhat arbitrary. Because they "lie on a continuum from specific to general . . . . most certainly there will be explanations that lie between the extremes" (A. Lawson, personal communication, December 20, 2010).

Second, consider "it is helpful to frame a testable hypothesis using 'if…then,' but not all hypotheses require this format" (Keeley, 2010, p. 25), which is used in conjunction with the author's assertion that a hypothesis need not be in the form of "if . . . then." I find this confused and confusing. At the heart of the scientific method (or hypothetical-deductive approach, as it is also called) is the generation and testing of hypotheses, which follows an "if...and…then…and/but…therefore…" (or, for brevity, "If/then/therefore") pattern of reasoning. That is, in trying to answer a causal question, we reason along the lines of "if this hypothesis (i.e., explanation) is correct, and we do this planned test, then we should get this result (i.e., the prediction). And/but when we do the test we get these results. Therefore, we can reach this conclusion about the hypothesis" (Eastwell, 2010). Ok, granted a hypothesis itself will not be in the form of "if…then," but it is a compulsory component of the "if..then" pattern of reasoning.

References

Eastwell, P. H. (2002). The nature of science. *The Science Education Review*, *1*, 43-48.
Eastwell, P. H. (2010). The scientific method: Critical yet misunderstood [Readers' Forum]. *The Science Education Review*, *9*, 8-12.
Keeley, P. (2010). To hypothesize or not? *Science and Children*, *48*(4), 24-26.
Lawson, A. E. (2008). *Biology: An inquiry approach* (2nd ed.). Dubuque, Iowa: Kendall Hunt.
Lawson, A. E. (2010). How ''scientific'' is science education research? *Journal of Research in Science Teaching*, *47*, 257-275.

Peter Eastwell, Science Time Education, Queensland, Australia

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Purpose of Mentos/Diet Coke Fountain

For what purpose(s) in science education (e.g., in connection with what content), and how, can the familiar Mentos in Diet Coke fountain be used in school science education?

Mentos + Diet Coke demonstrates well the nucleation from supersaturated solutions and complements nicely the well-known examples of supersaturated aqueous solutions of sodium acetate or sodium thiosulfate. These are both examples of supersaturated solutions of solids, and crystallization can be induced in several ways, enabling the audience to witness the growth of crystals in seconds. Mentos + Diet Coke is, however, a supersaturated aqueous solution of gas (CO_2), but the principles are the same. The Mentos pill has the role of a "seed," and once triggered, the process proceeds analogously to the process of crystallization from supersaturated solutions, except that it may be more spectacular.

Vladimir Petrusevski, Sts Cyril & Methodius University, Republic of Macedonia

If done properly, this is a very effective piece of practical work that can catch pupils' interest and be so useful as a starter or plenary session for a variety of lesson topics. Doing it outside is probably best. It also works well if you include pupils in the actual demonstration (e.g., one to hold the delivery tube for the mints, one to remove the barrier (so that mints fall in all together), and one to photograph or video the effect (ideally with a metre rule or similar in the background).

On a simple level, the demonstration can link to volcanoes. Mud around the coke bottle can simulate a mountain and miniature houses / hotels from a Monopoly set can represent villages. The devastation caused by the "eruption" can be recorded, and this is best achieved by taking "before" and "after" pictures.

An obvious application is any lesson about pressure, and I would suggest that it has a place with almost any age group as the sophistication of the explanation can match what is seen. The impact is large for the short time it takes to set up and do.

A further application is perhaps more advanced and more suitable for extension work or Science clubs and this links to what is really going on in terms of bubbles collecting on the microscopically pitted surface of the Mentos mints.

Additionally, with more time--again, perhaps during Science clubs--the basic demonstration could be extended by turning it into a pupil investigation. One of the cheap supermarkets in the UK sells 1-litre bottles of own brand Coke for one fifth the price of Coca Cola and these still work, thus reducing the cost of repeat performances. Pupils could investigate independent variables (e.g., type of mint, type of Coke, numbers of mints, and cutting the mints into smaller pieces) against dependent variables (e.g., height of fountain and volume ejected via measuring how much is left) and look at the effect of controlled variables (e.g., the temperature of the Coke [although this could also make an interesting independent variable]) and method of adding mints).

Sue Howarth, University of Worcester, UK

We use this in the Engage phase to show a physical change in a unit of work called Kitchen Science that looks at physical and chemical change. This unit incorporates the 5E enquiry model and is available from http://www.canecuttercluster.eq.edu.au/joomla/index.php?option=com_content&task=view&id=21&Itemid=31 .

Gerard Blackman, Flying Fish Point State School, Queensland, Australia

The major effect with the Coke and Mentos is due to nucleation. It turns out that nucleation is a central process in the water cycle, too. That is, rain forms thanks to nucleation (dust particles around which the water condensates and rain falls!). This is most evident when there is drought somewhere. You can get rain by dropping crystals into clouds to "seed" them. Water nucleates around the crystals and you get rain.

You also have dust particle in snowflakes (same concept except that the water freezes as it comes down). Here in Canada, my students do activities in class with their science teacher where they melt snowflakes to see the dust particles inside (though I'm not convinced that in urban areas, the dust is only from the nucleation process). You can see nucleation best in a translucid glass of soda pop. The bubbles always escape from the same place on the glass. Try it! You get a streamer from the same place. Most spots on the glass produce no bubbles. This is because you need a small flaw on the glass at which the bubbles will nucleate.

Nathaniel Lasry, Canada

This is a pertinent question since, although the effect is dramatic, there seems to be little connection with any learning or theory. It does however connect with a passionate interest of mine since I persuaded myself that fizzing drinks such as Diet Coke are actually examples of boiling solutions (Goodwin, 2001).

In the closed, pressurised container, the solution is at equilibrium well above its normal boiling point (from this perspective it is considered a solution of carbon dioxide in water, with other solutes having only a marginal effect on the boiling point). When the top is removed, the pressure on the surface of the Coke is reduced, but there are few nuclei on which bubbles can form (the manufacturer rigorously excludes these) unless the bottle has been shaken up just before opening to produce tiny bubbles of carbon dioxide and water vapour suspended in the liquid. These bubbles will act as nuclei and the Coke will fizz strongly. Otherwise, the solution remains fairly still and is not at equilibrium since it is supersaturated with carbon dioxide.

When a Mentos is added, the small particles of sugar in the surface act as nuclei for the formation of bubbles and the liquid “boils over” (i.e., they provide a kinetic pathway for the solution to move towards equilibrium). This boiling is an example of fractional distillation, with the carbon dioxide separating from most of the rest of the solution. The boiling point of the remaining solution gradually rises as the carbon dioxide escapes. I hope this provides a curriculum connection, still worthy of debate even if you are not yet convinced that fizzing drinks are boiling!

Alan Goodwin, Manchester Metropolitan University, UK

Reference

Goodwin, A. (2001). Fizzing drinks, are they boiling? *Journal of Chemical Education*, *78*(3), 385-387.

In my experience, teachers using the Mentos fountain demonstration are commendably seeking to engage students with an impressive phenomenon. But the opportunity to seize upon the resulting “teachable moment” can be all but lost when the teacher focuses on the nuances of the chemical/physical reaction itself, which as Tonya Coffey (2008) explained is really rather complicated. However, even very young and novice students can grasp the concepts of the states of matter (solids, liquids, and gasses) and that a given amount of a substance will generally take up more volume as a gas than as a liquid.

The state of a substance, and its relative volume, can be demonstrated quite well via the Mentos fountain, which gets its explosive power from the rapid conversion of carbon dioxide in a dissolved liquid state to its native gaseous form, wherein it takes up much more volume than the bottle can contain. This can be explained without going into the interactions between the surfactant properties of the Mentos gum arabic coating, the surface area to volume ratio of the rough candy surface, the surface-tension-lowering action of the aspartame in Diet Coke, the density of the candy, chain reactions among the bubbles as they “seed” the formation of other bubbles, and so on (Coffey, 2008).

But whether or not teachers endeavor to explain the wherefores of the Mentos/Diet Coke effect, there are abundant opportunities for extensions to other concepts. For example, the fountain effectively demonstrates that gases really can be dissolved in liquid solvents. This has implications for teaching about transportation of oxygen and carbon dioxide in circulatory systems. And what influence might pressure have on gases in solution? When you open a bottle of soda, the fizz and bubbling as the pressure in the bottle is released is analogous to what happens in the blood of scuba divers who surface too quickly. Decompression sickness, or "the bends," results when higher concentrations of dissolved nitrogen in the blood develop under high pressure conditions at depth. If the diver returns to the surface too rapidly, the decrease in pressure can lead to the rapid dissolution of nitrogen as bubbles, just like the CO_2 in the soda. A more advanced extension of the gas/liquid volumetric difference might be the function of the swim bladders of many kinds of fish, in which the organ of buoyancy control is deflated or inflated by sequestering or liberating gases into or out of solution in the blood (Plester & Scheid, 1992). For these last two examples, the Mentos fountain might be used as a sort of example in the extreme for reinforcing the underlying concepts.

Jason R. Wiles, Syracuse University, New York, USA

References

Coffey, T. S. (2008). Diet Coke and Mentos: What is really behind this physical reaction? *American Journal of Physics*, *76*, 551-557.

Plester, B., & Scheid, P. (1992). Countercurrent concentration and gas secretion in the fish swim bladder. *Physiological Zoology*, *65*(1), 1-16.

Laboratory Safety Guidelines

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

#13 of 40. ***Don't Allow Experiments to Run Unattended Unless They are Failsafe***

There are surely going to be times when experiments must continue running on their own while you do other things (e.g., go out to lunch or home to sleep). At these times, it's important to consider all the things that could go wrong in your absence and to prepare for them.

For example, what would happen if there were a power or compressed air failure and the stirrer were to shut down? What if the water gets turned off or a cooling hose detaches? Get the idea? Cooling hoses need to be clamped or wired on.

What about the water shut down? Do you need a special sensor for water, temperature, pressure, fluid level, etc. to control the experiment in your absence?

The name, address, and phone number of the person responsible for an experiment should be prominently displayed. In addition, clear directions should be provided on how to safely shut down the experiment in your absence. Special hazards and precautions should be noted. Your experiment shouldn't become someone else's land mine.

One of Dow's policies was the unattended experiments should be set up in such a way that they are "fail safe." They automatically shut down if a failure occurs rather than create a runaway situation (overheating or over pressurizing).

Further Useful Resources

The Meaningful Learning Research Group (http://www.mlrg.org/) This is the home of the proceedings of the four international Research on Misconceptions in Science and Mathematics conferences (with the proceedings of the 3rd and 4th conferences available as full text). Also contains useful tools, such as the concept-mapping program CmapTools, and more.

Understanding Science: How Science Really Works (http://undsci.berkeley.edu/) Communicates what science is and how it really works. The project aims to improve teacher understanding of the nature of the scientific enterprise, provide resources and strategies that encourage and enable K-16 teachers to reinforce the nature of science throughout their science teaching, and provide a clear and informative reference for students and the general public that accurately portrays the scientific endeavour.

Rubistar (http://rubistar.4teachers.org/index.php) Facilitates the creation of rubrics, and includes templates.

MyScience (http://myscience.com.au/) A pioneering primary science initiative that uses a distinctive team approach, with primary teachers, primary students, and volunteer mentor scientists working collaboratively as the students conduct authentic scientific investigations to find answers to their own questions.

SCRATCH (http://scratch.mit.edu/) A free, downloadable program that allows students to use computer-animation technology to create stories, games, music, and art (e.g., short cartoons to explain scientific concepts). The program, designed for primary and middle school students, uses simple blocks of commands for movement, looks, and sounds that students can fit together to command their animated objects ("sprites") to move and speak.

Implementing Science-Technology-Society Approaches in Middle School Science Teaching

Hakan Akcay[1] and Robert E. Yager[2]
[1] *Yildiz Technical University, Istanbul, Turkey* hakanakcay@gmail.com
[2] *University of Iowa, Iowa City, IA, USA* robert-yager@uiowa.edu

Abstract

The National Science Education Standards emphasize a goal that students should achieve scientific literacy, which is defined as the knowledge and understanding of scientific concepts needed in daily living. Scientific literacy enables people to not only use scientific principles and processes in making personal decisions but also to participate in discussions of scientific issues that affect society. Understanding scientific knowledge and processes contributes in an essential way to these skills. The economic productivity of society is related to the scientific and technological skills of the people. The results of this study indicate that students in the student-centered STS sections achieved significantly better than students in the teacher-directed STS sections in terms of understanding and use of process skills, use of creativity skills, development of more positive attitudes; and the ability to apply science concepts in new contexts. (This paper is a summary of Akcay & Yager, 2010)

The reform movement characterizing Science, Technology, and Society (STS) contributes to the goal of scientific literacy (National Science Teachers Association [NSTA], 2007; Yager, 1996). STS provides direction for achieving scientific and technological literacy for all. The emphasis is on responsible decision-making in the real world of the student where science and technology are both components. The National Science Teachers Association defines the STS approach as the teaching and learning of science and technology in the context of human experiences (NSTA, 2007).

STS means focusing upon current issues, and attempts at their resolution, as the best way of preparing students for current and future citizenship roles. This means identifying local, regional, national, and international problems with students, planning for individual and group activities that address them, and moving to actions designed to resolve the issues investigated. STS is meant to provide a means for achieving scientific and technological literacy for all. The emphasis is on responsible decision-making in the real world of the student where science and technology are both important components. Technology is of more interest to most people than is pure science. Technology is a focus on the human-made world where the designs are aimed at providing observable products that directly affect humans (e.g., air travel, refrigeration, T.V., cell phones, transportation, machines, and buildings). To be considered STS, the reforms envisioned and characterized include eleven basic features that are central to the NSTA policy statement regarding STS. These include:

1. student identification of problems with local interest and impact;
2. the use of local resources (human and material) to locate information that can be used in problem resolution;
3. the active involvement of students in seeking information that can be applied to solve real-life problems;
4. the extension of learning beyond the class period, the classroom, the school;
5. a focus upon the impact of science and technology on each individual student;
6. a view that science content is not something that exists merely for students to master on tests;

7. a de-emphasis upon process skills *per se* just because they represent glamorized skills used by practicing scientists;
8. an emphasis upon career awareness--especially careers related to science and technology;
9. opportunities for students to perform in citizenship roles as they attempt to resolve issues they have identified;
10. identification of ways that science and technology are likely to impact the future;
11. some autonomy in the learning process as individual issues are identified and used to frame instruction.

(NSTA, 2007, p. 242)

The Chautauqua Professional Development Program

The Chautauqua Professional Development Program was conceived in 1983 as a way to introduce changes in teaching that exemplify the STS approach for teaching science. It is an in-service model for improving science teachers and science education programs that has developed over the past three decades. The staff development model was designed to assist teachers in changing their goals, curricula, and teaching strategies. The model has been singularly successful in meeting basic goals advanced by STS efforts and later identified as new directions in the National Science Education Standards (NSES) (National Research Council [NRC], 1996). The Standards recommend the collection of assessment data over time, a practice designed to change teaching, assessment strategies, and inquiry-oriented methods. Specific program goals include:

1. improving teacher confidence for teaching science;
2. changing the focus of teachers to make their teaching more congruent with the features of basic science, and those more specifically envisioned in the National Science Education Standards; and
3. preparing science teachers as leaders who can help their own students improve in five domains of learning science.

These domains comprise:

1. *Concept domain* (mastering basic content constructs): Science aims to categorize the observable universe into manageable units for study and to describe physical and biological relationships. Ultimately, science aims to provide reasonable explanations for observed relationships. Part of any science instruction may involve learning by students in terms of the information developed over time through scientific pursuits of the past. The concept domain includes facts, concepts, laws (principles), and existing hypotheses and theories being used by scientists. This vast amount of information is usually classified into such manageable topics as matter, energy, motion, animal behavior, and plant development.
2. *Process domain* (learning skills scientists use as they seek answers to their questions about the natural world): Scientists use certain identifiable processes (skills). Being familiar with these processes concerning how scientists think and work is an important part of learning science. Some processes of science are observing and describing, classifying and organizing, measuring and charting, communicating and understanding, communicating with others, predicting and inferring, hypothesizing, hypothesis testing, identifying and controlling variables, interpreting data, and constructing instruments, simple devices, and physical models.
3. *Creativity domain* (improving the quantity and quality of questions, explanations, and tests for the validity of personally generated explanations): Most science programs view a science program as something to be done to students to help them learn a given body of

information. Little formal attention has been given in science programs to the development of students' imagination and creative thinking. Little has been done to encourage curiosity, questioning, explaining, and testing--all the basic ingredients of science. Some of the specific human abilities important in this domain are visualizing (i.e., producing mental images), combining objects and ideas in new ways, producing alternative or unusual uses for objects, solving problems and puzzles, designing devices and machines, and producing unusual ideas. Much research and development has been done on developing students' abilities in this creative domain, but little of what has been learned about creativity has been purposely incorporated into science programs.

4. *Attitude domain* (developing more positive feelings concerning the usefulness of science, science study, science teachers, and science careers): In these times of increasingly complex social and political institutions, environmental and energy problems, and general worry about the future, scientific content, processes, and even attention to imagination are not sufficient parameters for science programs. Human feelings, values, and decision-making skills need to be addressed. This domain includes developing positive attitudes toward science in general, science in school, and science teachers, developing positive attitudes toward oneself (an "I can do it" attitude), exploring human emotions, developing sensitivity to, and respect for, the feelings of other people, expressing personal feelings in a constructive way, making decisions about personal values, and making decisions about social and environmental issues.
5. *Application domain* (using concepts and processes in new situations): It seems pointless to have any science program if the program does not include some substantial amount of information, skills, and attitudes that can be transferred and used in students' everyday lives. Also, it seems inappropriate to divorce "pure" or "academic" science from technology. Students need to become sensitized to those experiences they encounter that reflect ideas they have learned in school science. Some dimensions of this domain are seeing instances of scientific concepts in everyday life experiences, applying learned science concepts and skills to everyday technological problems, understanding scientific and technological principles involved in household technological devices, using scientific processes in solving problems that occur in everyday life, understanding and evaluating mass media reports of scientific developments, making decisions related to personal health, nutrition, and life-style based on knowledge of scientific concepts rather than on "hear-say" or emotions, and integrating science with other subjects. For many, the applications of science can provide the entry to the knowledge and process domains. For others (probably a definite minority), applications represent moves to the use of science known and developed over time. Many in education are looking to technology (the application of science concepts) or the applications domain as a starting point for indicating reform in K-12 classrooms.

(Enger & Yager, 2001, 2009; Yager & Akcay, 2007)

The Chautauqua Program operates on a continuing basis and an annual sequence of events describes its basic features that have been validated by the National Diffusion Network as a model for use elsewhere. These features can be abbreviated as follows:

1. A 2-week leadership conference for some of the most successful teachers from previous years who want to become a part of the instructional team for future workshops.
2. A 3- to 4-week summer workshop at each new site for 30 new teachers electing to try inquiry teaching and learning strategies. The workshop provides experience with inquiry (teachers as students) and time to plan a 5-day inquiry unit to be used as a pilot with students in the fall.

3. A 3-day fall short course for 30-50 teachers (including the 30 enrolled during the summer) focusing on developing a month-long inquiry module and an extensive assessment plan.
4. Interim communications with central staff, lead teachers, and fellow participants via a newsletter, special memoranda, monthly telephone contacts, and school/classroom visits.
5. A 3-day spring short course for the same 30-50 teachers who participated in the fall. This session focuses on reports by participants about their inquiry experiences and the results of the assessment program. The emphasis is on sharing successes and failures while also planning more fall inquiry courses. Every attempt is made to model inquiry teaching techniques by all staff members for the workshop. Action research projects are encouraged by staff members, teacher participants, and students in the classrooms of participants.

The Chautauqua Program is an example of teachers helping teachers with new curriculum modules and especially new approaches to instruction. The new directions are exemplified by cutting-edge science curricula developed around the world. The Chautauqua Program requires a commitment on the part of participants to try, assess, and experiment with instruction often suggested by the most innovative new curricula. Every participant becomes a part of the effort and adds to the information and experience base of the total group. Unlike many other in-service programs, information has been amassed over a 28-year period concerning the successes of the program. It is a program that produces changes in the perceptions of teachers about science teaching.

This study was to examine the effectiveness of the Chautauqua Professional Development Program in terms of improving student: 1) concept mastery, 2) ability to define and use process skills, 3) development of more positive attitudes regarding science, 4) development of specific creativity skills, and 5) ability to use major concepts in new situations. Differences between student successes in teacher-centered STS sections and those in largely student-centered sections were sought among the 12 teachers involved, each with one regular STS section and the other with an almost complete focus on students identifying their own issues, their own proposed solutions, their own search for validity of their hypotheses, and their own solutions to the issues they identified.

Overview of Data Set

Our study involved 12 teachers who agreed to collect pre- and post-assessment information in the five assessment domains for students in one section where the teacher guided instruction, prepared daily lesson plans, and structured the STS modules for the 9-week grading period, the semester, and/or the entire academic year. Another section was established as the experimental one where the STS teaching consistently focused on student-centered teaching and learning methods. A total of 724 students were involved from Grades 6 through 9. The Assessment Handbook for the Chautauqua Program provided the instruments and procedures used to collect data (Enger & Yager, 2001, 2009). The assessment handbook includes samples, test features, and scoring directions with new samples added each Chautauqua year--all developed and used by the enrolled teachers. A quasi-experimental design was used. The same instruments were used as pre-tests and post-tests. The pre-tests were given at the beginning of the semester. The teachers involved were active mentors for new teachers enrolled in Chautauqua sites designed to help teachers use more student-centered STS strategies in their daily teaching. The post-tests were given at the end of the semester. The data were analyzed quantitatively by reporting means and standard deviations. The differences in mean values were tested using a t-test for determining significances. The mean differences, standard deviations, and t- values were calculated and used to assess differences between pre- and post-test scores in the five domains for all students in both class sections for each of the 12 teachers. A 5% level of significance ($P \leq 0.05$) was used to assess statistical differences.

Findings

In order to evaluate the effects of more student-centered STS instruction, comparisons were made between students taught using teacher-guided STS and those in classes where the primary focus was on student-centeredness with respect to the five domains. The findings of our study can be summarized as follows:

- Students experiencing the student-centered STS instructional approach were as successful as students in sections where the focus was almost totally on concept mastery (and to a lesser degree on process skills used in laboratories).
- Students experiencing student-centered STS instruction were significantly better in terms of use of science process skills in new situations and understanding of the nature and importance of such skills.
- The students who experienced science in the student-centered STS sections were able to demonstrate greater creativity in terms of questioning and hypothesizing skills than students in the teacher-directed sections for all grade levels. This included creativity in asking questions, proposing answers, testing for validity of hypotheses offered, use of the ideas and skills, and conceptualizing consequences for specific corrective actions.
- Students in the student-centered STS sections proved to be the more successful in improving attitudes, while those in the teacher-centered sections largely remained the same. In some cases, student attitudes actually worsened significantly in the teacher-directed sections.
- The application items illustrate student use of the major concepts and process skills characterizing the science concepts used at each of the four grade levels. The greatest success of students in student-centered STS sections occurred in the use of the concepts and skills in completely new situations as chosen and proposed by students. Information was collected via teacher tests where students had to recognize appropriate use of the concepts and skills in new situations. In addition, students were asked in an open format to identify and prepare such applications and discuss them as an indicator of the learning of all students enrolled in a particular section.

Discussion and Implications

James Rutherford was one of the first to recognize that real change in the instructional procedures in schools, as well as the curriculum structure, require time. His thinking is exemplified by *Project 2061: Science for all Americans* (American Association for the Advancement of Science [AAAS], 1989), which notes the next appearance of Haley's Comet from Earth as being a more realistic expectation than educational change. He argued that real change in school science will take 75 years--the likely lifetime of humans. *Science for all Americans* was the most comprehensive view of needed reform in the U.S. during the past 18 years. Its use impacted the development of the NSES. One major change has been the reunion of science and technology (i.e., considerations of the natural world and the human-made world). Involving engineers in school science program was a welcomed change that has enjoyed significant National Science Foundation (NSF) support. But, these programs retained the focus on curriculum, both in terms of textbooks and shorter modules. Most did not focus primarily on teaching as a new approach and/or as an important ingredient for successful learning. Some of the programs enjoyed support, trial use, and success with needed reforms. Some were involved with collecting evidence about the advantages of STS teaching in general. Being focused on the design world and headed by engineers are important changes, but also result in setbacks from lack of support and leverage gained by more typical reform projects and only small changes were adopted by major textbooks that tend to depend almost completely on the traditional course content found in typical textbooks. They did not fit well with existing curricula, leadership strategies, standard assessments, state frameworks, or features required by textbook adoption states (about 17). It is probably fair to note that the most innovative programs are seldom in general demand and the publishing companies they attract are not "main stream."

The following are five examples of new STS and design-world programs where student-centeredness for reforms can easily be added:

1. The Man-Made World (ECCP), Polytechnic Institute of Brooklyn (1971)
2. Integrated Mathematics, Science, and Technology (IMaST), Illinois State University (1994)
3. Teaching Science Through Science/Technology/Society (S-STS), Pennsylvania State University (1984)
4. Material World Modules (MWM), College of Engineering Northwestern University (1996)
5. Science and Technology for Children (STC), Smithsonian Institution (1996).

Further, study designs also improve when ideas emerge from individuals or small groups of students. Their voices and actions may be more important than curricular frameworks provided by others.

These programs all indicate STS initiatives and changes yet to be commonly found in schools. Although all wanted to be student-centered, none were so described fully. None of these STS reform programs succeeded in changing actual teaching in school programs. They reported progress that openly included technology and science while suggesting new teaching approaches that encouraged use of constructivist perspectives. Such a perspective when emphasized led to more student-centered efforts.

STS efforts have been criticized for not advancing specific curriculum structures (such as the "design world" examples of STS indicated above). But they indicate the problems of curricula that are offered as "teacher-proof" pathways to reform. It is impossible to conceive of any STS effort in a textbook without use of contemporary problems that are personally relevant, current in terms of importance, and experienced and found locally. Some have called such STS approaches to be concerned with "me, here, and now." Such efforts by definition tend to be student-centered. Few curriculum reforms are personally relevant, deal with local issues, and exemplify current concerns. Few have taken seriously the eight facets of content spelled out in the NSES: 1) Unifying concepts and processes in science, 2) Science as inquiry, 3) Physical science, 4) Life science, 5) Earth and space science, 6) Science and technology, 7) Science in personal and social perspective, and 8) History and nature of science. Few focus primarily on instruction and a truly student-centered curriculum. And yet these are attributes that are necessary ingredients for achieving the reforms--and possibly in less than the 75 years Rutherford foretold. The question concerning the degree of student versus teacher centeredness remains.

More attention may need to be paid to teachers and their teaching, as exemplified in the NSTA Exemplary Science Program series. Present titles comprise *Exemplary Science in Grades PreK-4* (Yager & Enger, 2006), *Exemplary Science in Grades 5-8* (Yager, 2006), *Exemplary Science in Grades 9-12* (Yager, 2005b), *Exemplary Science Best Practices in Professional Development*

(Yager, 2005a), *Exemplary Science in Informal Educational Settings* (Yager & Falk, 2008), *Inquiry: The Key to Exemplary Science* (Yager, 2009), and *Exemplary Science for Resolving Societal Challenges* (Yager, 2010).

What have been found to be exemplary in meeting the visions of the NSES prove to be exciting examples of the implemented reforms. The data reported in this study provide real evidence that the reforms have been successful with students and provide pathways that have been used by over 200 teachers who have shared evidence of successes for their teaching ideas and descriptions of the associated effects with student learners. This study indicates the power of student-centered instruction over teacher-centeredness in five domains advanced for assessment.

References

Akcay, H., & Yager, R. E. (2010). The impact of a science/technology/society teaching approach on student learning in five domains. *Journal of Science Education and Technology*, *19*, 602-611.

American Association for the Advancement of Science (AAAS). (1989). *Project 2061: Science for all Americans*. Washington, DC: American Association for the Advancement of Science.

Enger, S. K., & Yager, R. E. (2001). *Assessing student understanding in science*. Thousand Oaks, CA: Corwin Press.

Enger,S. K., & Yager, R. E. (2009). *Assessing student understanding in science* (2nd ed.). Thousand Oaks, CA: Corwin Press.

National Research Council (NRC). (1996). *National science education standards*. Washington, DC: National Academic Press.

National Science Teachers Association (NSTA). (2007). *Science-technology-society* (NSTA position statement). Washington, DC: National Science Teachers Association.

Yager, R. E. (1996). *Science/technology/society as reform in science education*. Albany, NY: State University of New York Press.

Yager, R. E. (2005a). *Exemplary science best practices in professional development*. Arlington, Virginia: NSTA Press.

Yager, R. E. (2005b). *Exemplary science in Grades 9-12: Standards-based success stories*. Arlington, Virginia: NSTA Press.

Yager, R. E. (2006). *Exemplary science in Grades 5-8: Standards-based success stories*. Arlington, Virginia: NSTA Press.

Yager, R. E. (2009). *Inquiry: The key to exemplary science*. Arlington, Virginia: NSTA Press.

Yager, R. E. (2010). *Exemplary science for resolving societal challenges*. Arlington, Virginia: NSTA Press.

Yager, R. E., & Akcay, H. (2007). What results indicate concerning the successes with STS instruction. *Science Educator*, *16*(1), 13-21.

Yager, R. E., & Enger, S. K. (2006). *Exemplary science in Grades PreK-4: Standards-based success stories*. Arlington, Virginia: NSTA Press.

Yager, R. E., & Falk, J. (2008). *Exemplary science in informal education settings: Standards-based success stories*. Arlington, Virginia: NSTA Press.

Simple Demonstration of the Seebeck Effect

Arman Molki
The Petroleum Institute, Abu Dhabi, United Arab Emirates
amolki@pi.ac.ae

Abstract

In this article we propose a simple and low-cost experimental set-up through which science educators can demonstrate the Seebeck effect using a thermocouple and an instrumentation amplifier. The experiment can be set up and conducted during a 1-hour laboratory session.

When a temperature gradient is introduced along the length of a metal wire, electrons start to diffuse from one end to the other end of the wire (Chambers, 1977). The direction of electron diffusion depends on the electrical properties of the metal wire. By convention, if electrons diffuse from the hot end towards the cool end of the wire, a negative thermoelectric emf is generated in the wire with respect to the hot end. Similarly, if electrons diffuse from the cool end towards the hot end of the wire, a positive thermoelectric emf is generated in the wire with respect to the hot end. This phenomenon in metals, known as the Seebeck effect, was first observed by physicist Thomas Johann Seebeck (1770-1831). Seebeck observed that when two dissimilar metal wires are formed into a closed loop and its two junctions are held at different temperatures, it has the ability to deflect a galvanometer needle. The phenomenon was later attributed to electrical current through the wires.

Metals have different thermoelectric sensitivities, or Seebeck coefficients. For example, iron has a Seebeck coefficient of 19 μV/°C at 0°C, which means that for every 1°C difference in temperature, a positive thermoelectric emf (or Seebeck voltage) of 19 μV is induced in iron at temperatures around 0°C. As mentioned in the previous paragraph, a negative thermoelectric emf can also be induced in a metal, so Seebeck coefficients can also have negative values. For example, constantan (a copper-nickel alloy) has a Seebeck coefficient of -35 μV/°C at 0°C. It should be noted that the relationship between Seebeck voltage and temperature is linear only for small changes in temperature. For larger temperature ranges, the relationship becomes non-linear. It is therefore important to state the temperature at which the Seebeck coefficient is being specified.

A thermocouple is made from two dissimilar metals that are co-joined at one end (Figure 1) and can be used as a temperature sensor. As shown in Figure 1, a thermocouple consisting of metal A with Seebeck coefficient α_A and metal B with Seebeck coefficient α_B produces a thermoelectric emf (E) which is a function of the temperature of its tip (T_1), the temperature of the measuring point (T_2), and the thermocouple's Seebeck coefficient ($\alpha = \alpha_A - \alpha_B$). The relationship is mathematically expressed in Equation 1.

$$E = \alpha(T_1 - T_2) \qquad (1)$$

The operation of a thermocouple is based on the different Seebeck coefficients of the dissimilar metals. If the two metals of the thermocouple were alike, or had the same Seebeck coefficient, the net emf produced at its measuring point would be zero. To measure the Seebeck voltage generated by a thermocouple, one can either use commercially available thermocouple readers or establish one's own thermocouple circuit. The reader may find it useful to review existing literature and become familiar with the different types of thermocouple circuits (Omega, n.d.). Since thermocouples are relative temperature sensors, a thermocouple circuit requires a known reference temperature, such as an ice bath, for proper operation.

Figure 1. Schematic of a thermocouple made of metal A, with Seebeck coefficient α_A, and metal B with Seebeck coefficient α_B.

The Experiment

For our demonstration, we set up the thermocouple circuit shown in Figure 2. Table 1 provides a list of the major components used in the set-up. Our set-up includes two J-type thermocouples, each consisting of a pair of iron and constantan wires that are welded at one end. One of the thermocouples is used for measuring the reference temperature (T_{Ref}), while the other thermocouple is used for measuring the ambient temperature (T). To make the connection between the constantan wires of each thermocouple, we simply twisted them together. Since the magnitude of the Seebeck voltage generated in the setup is of the order of a few µV, an instrumentation amplifier was used to amplify the magnitude of the voltage. Analog Digital instrumentation amplifier AD620 (Analog Devices, 2004) was employed for this purpose. The AD620 chip provides a low-cost and accurate amplification mechanism to amplify the generated thermo-electric emf such that it can be easily measured with a digital multi-meter or data logger. The AD620 chip requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 chip requires lower power (only 1.3 mA maximum supply current), making it a suitable selection for battery-powered or portable applications.

We powered our AD620 chip using a +/-15-V DC power supply. The gain (G) of the AD620 chip was set using a single resistor (resistance R_G) and calculated using Equation 2. In our circuit, we used a 220-Ω resistor, thereby obtaining a gain of 225.

$$G = \frac{49{,}400\Omega}{R_G} + 1 \qquad (2)$$

Our temperature reference point consisted of crushed ice and distilled water mixed inside an insulated flask. It is important to keep the reference thermocouple inside the ice bath during the entire demonstration. To increase the accuracy of our measurements, the connections from the thermocouple ends to the AD620 chip were made through an isothermal block. The isothermal block helps in keeping the connections at the same temperature and thus minimizing errors due to unwanted parasitic thermocouples created at the connections between the thermocouple ends and the AD620 input. We established an isothermal block using a barrier strip attached to a flat copper bar. Copper was chosen due to its high thermal mass. Thermal paste was applied between the barrier strip and the copper bar to enhance heat transfer. However, for the sake of simplicity, demonstrators may exclude the isothermal block and connect the thermocouple ends directly to the AD620 chip.

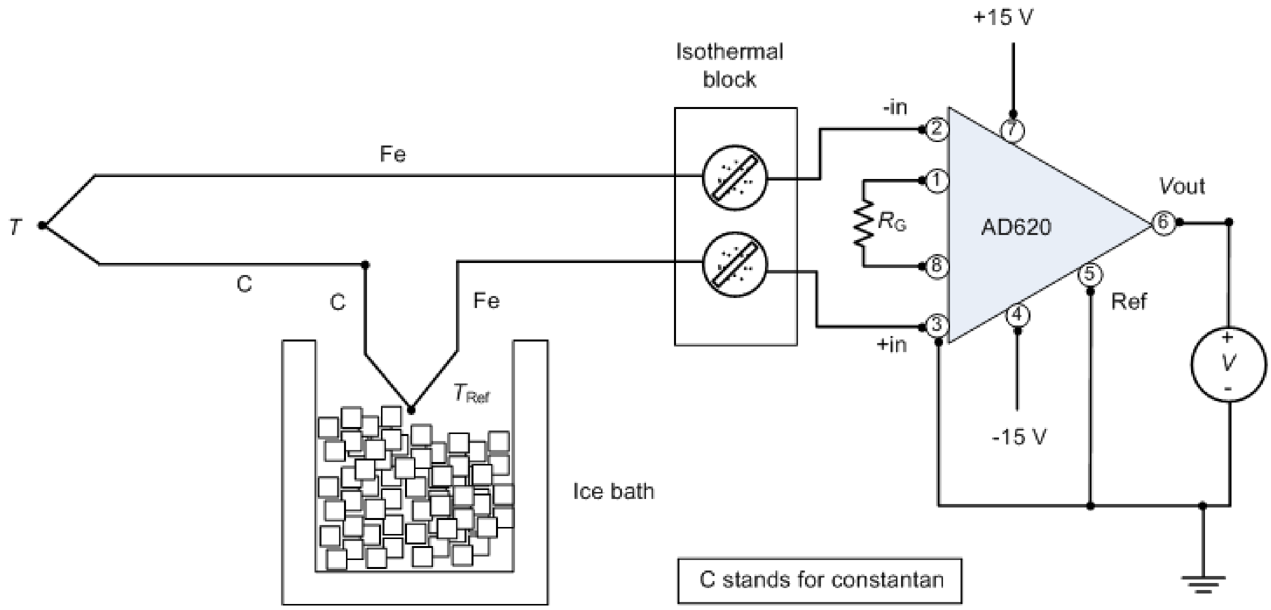


Figure 2. The thermocouple circuit.

Table 1
List of Major Equipment and Suggested Suppliers

Item	Qty	Supplier	Part Number	Unit Price (USD)
J-type thermocouple	2	RS Components	621-2186	10
AD620 instrumentation amplifier	1	Futurlec	AD620AN	5
220-Ω resistor	1	-	-	-
Digital multimeter	1	-	-	-
Insulated flask	1	-	-	-
Electric kettle	1	-	-	-
+/-15-V DC power supply	1	-	-	-
Breadboard	1	-	-	-
Copper bar (optional)	1	-	-	-
Barrier strip (optional)	1	RS Components	423-330	7
Thermal paste (optional)	1	RS Components	217-3835	20

Once all the connections are made (see Figure 3), the operation of the circuit can be quickly verified by turning on the power supply and holding the thermocouple bead (temperature *T*, as shown in Figure 2) between two fingers. If the digital multi-meter registers a sudden increase in the output voltage of the AD620 chip, then the circuit is most likely configured correctly. If not, the connections need to be re-examined.

The Seebeck effect can be demonstrated by subjecting the measuring thermocouple to various temperatures and recording the generated Seebeck voltage. For example, when we subjected the thermocouple to room temperature we registered an amplified Seebeck voltage of 257 mV. In order to obtain the actual (pre-amplified) Seebeck voltage (*E*), one must divide the amplified voltage by the circuit gain (*G*). In this case, we divided 257 mV by our gain of = 225 to obtain an actual Seebeck voltage of $E = 1.14$ mV. To further demonstrate the Seebeck effect, we submerged the measuring thermocouple in both an ice bath and then a kettle containing boiling water. Based on our measurements, we calculated actual (pre-amplified) Seebeck voltages of 0 mV and 5.23 mV respectively. The recorded Seebeck voltages can be easily converted to temperature using either reference tables or inverse polynomials as defined by the International Temperature Scale of 1990, ITS-90 (U.S. Secretary of Commerce, 1995). Table 2 summarizes our measurements and their corresponding calculated temperatures using the ITS-90 J-type thermocouple reference table.

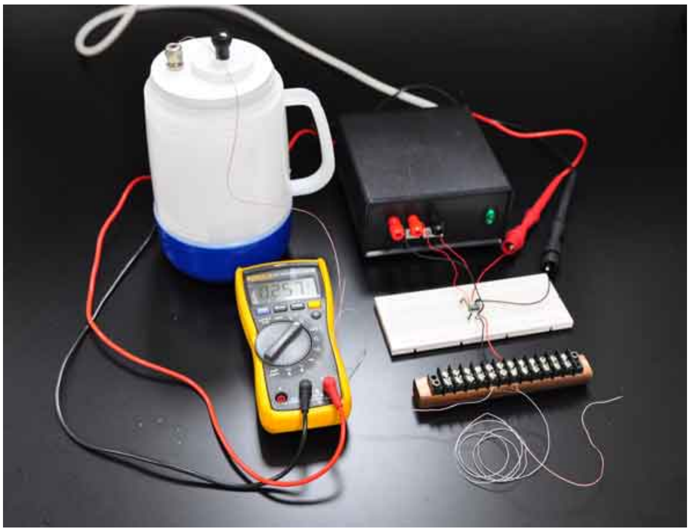


Figure 3. The experimental set-up.

Table 2
Measurements Using a J-Type Thermocouple With Gain of 225 and Ice/Water as Reference Temperature

Ambient condition	Amplified voltage (mV)	Pre-amplified voltage (mV)	Calculated temperature (°C)
Ice bath	0	0	0.0
Room temperature	257	1.14	22.5
Boiling water	1,177	5.23	99.5

The circuit can be used with other thermocouple types. Table 3 summarizes our voltage measurements and their corresponding calculated temperatures using the ITS-90 K-type thermocouple reference table. From the obtained results, it is easy to see that the J-type thermocouple has a higher sensitivity than the K-type thermocouple.

If class time permits, the instructor and students may find it rewarding to use the circuit to measure other known temperatures (e.g., the melting points of different solids or the boiling points of different liquids) and compare the results with published data.

Table 3
Measurements Using a K-type Thermocouple With Gain of 225 and Ice/Water as Reference Temperature

Ambient condition	Amplified voltage (mV)	Pre-amplified voltage (mV)	Calculated temperature (°C)
Ice bath	0	0	0.0
Room temperature	200	0.89	22.5
Boiling water	917	4.08	99.5

To ensure that students have understood the concepts and applications related to the Seebeck effect, it is recommended that a discussion session be conducted following the lab. During the discussion, a series of questions such as the following might be presented to the class:

- Describe the phenomenon observed by Seebeck.
- Why do metals have different Seebeck coefficients?
- Explain why some metals have positive Seebeck coefficients while others have negative coefficients.
- How does a thermocouple work? Why are thermocouples made from two dissimilar metals?
- What is the purpose of using an instrumentation amplifier?
- Why is an ice bath used as the reference temperature? Can other fixed temperatures be used?
- What is the purpose of using an isothermal block? What is a suitable material for the block and why?
- What is the ITS-90 reference table?
- Describe the thermocouple's voltage-temperature relationship. Is the relationship linear?

In Conclusion

We have described a simple and low-cost experimental setup through which science educators can demonstrate the Seebeck effect using a commercial thermocouple and an instrumentation amplifier. The experiment can be set up and conducted during a 1-hour lab session and followed by an in-class discussion. Science educators may find it particularly rewarding to expand the experiment by utilizing a computer-based data acquisition system to record the generated Seebeck voltage in real time and convert the recorded data to temperatures.

References

Analog Devices. (2004). *Low cost, low power instrumentation amplifier: AD620*. Retrieved from http://www.analog.com/static/imported-files/data_sheets/AD620.pdf .

Chambers, R. G. (1977). Thermoelectric effects and contact potentials. *Physics Education, 12*(6), 374-380.

Omega. (n.d.). *The thermocouple*. Retrieved October 10, 2010, from http://www.omega.com/temperature/z/pdf/z021-032.pdf .

U.S. Secretary of Commerce. (1995). *NIST ITS-90 thermocouple database*. Available from http://srdata.nist.gov/its90/main/ .

The Science Education Review (ISSN 1446 - 6120) is published by Science Time Education, 570 Womina-Willowvale Road, Warwick, Queensland 4370 Australia.

The Science Education Review (*SER*) is an international, peer-reviewed periodical aiming to provide primary and high school teachers with the latest, and best, ideas in science education from around the world. *SER* also publishes original articles, including research articles, and much more.

Please visit ***The Science Education Review*** at http://www.ScienceEducationReview.com . ***SER On-Line*** offers individuals and institutions password and/or IP authenticated access to the content of all issues of *SER*.

Contributions are welcome, as are expressions of interest in joining the Editorial Review Board. The latter role requires the periodic review of submitted contributions, and is not onerous. Comments, questions, and article proposals may be sent to The Editor, Dr Peter H. Eastwell, at editor@ScienceEducationReview.com .

*   *   *

The Science Education Review

Table of Contents

Volume 9, Issues 1-3, 2010

Did you Know?

Articles

Teaching Ideas

Science Poetry

Research in Brief

Reader's Forum

Your Questions Answered

Laboratory Safety Guidelines

Further Useful Resources