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THE SCIENCE EDUCATION REVIEW

Ideas for enhancing primary and high school science education

Did you Know?

Nuclear Radiation Surrounds Us

The word *radioactive* was invented by Marie Curie (1859-1934) in 1898, but it wasn't till the early 1920s that scientists came to realize the dangers of nuclear radiation. Prior to this, radioactive material had actually been added to makeup to provide extra sparkle!

However, we are exposed to a variety of radioactive sources--some natural and some manufactured--daily. All samples of potassium, for example, are slightly radioactive, because they contain 0.0118% of the unstable isotope potassium-40, which is a β-emitter. Everyday things that contain potassium include garden soil, bananas, and the potassium chloride/sodium chloride mix used as a substitute by those wanting to adopt a low-salt diet.

Science Story

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

Did Thomas Edison Invent the Light Bulb?

In 1801, Sir Humphrey Davy used electricity to make platinum (Pt) strips glow in air, thus demonstrating the principle behind the incandescent light bulb (i.e., a bulb that produces light from an electrically-heated filament). Of course, the Pt reacted with oxygen in the air and burnt out quickly. However, contrary to widespread belief, Thomas Edison did not invent the incandescent bulb, but rather improved on 50-odd years of previous work that included the following:

- 1820: Warren De la Rue passed electricity through Pt in a vacuum tube, but Pt was too rare and expensive for everyday use.
- 1841: Frederick de Moleyns took out the first patent for an incandescent bulb in which electricity passed through powdered charcoal. The life-span of the bulb was short.
- 1874: Henry Woodward and Matthew Evans (Canada) patented a light bulb that used a vacuum to prevent the metal burning. They were ridiculed by locals, though, who wondered who would ever need a glowing piece of metal!

- 1878: Hiram Maxim filled a carbon-filament bulb with petrol vapour (which, in the absence of oxygen, will not burn).

Realising how valuable the patents were, in 1879 Edison bought them all. Sir Joseph Wilson Swan (England,1878) and Edison (USA,1879) competed to produce a bulb with a longer life, with both arriving at the idea of a carbon filament in a vacuum that lasted a day or so, suing each other for patent violation in the process. Eventually, they combined forces to form the Ediswan Company (which in 1892 became General Electric).

While Edison and his team did experiment with over 6000 different materials for a filament before deciding on tungsten, he does seem to receive all the credit for the invention of the incandescent light bulb. This is probably due to the fact that he registered so many patents--1093 in all--that people assumed he must have invented the concept, and also because of the attention he attracted by developing a practical lighting system--incorporating power plant, voltage and current controls, circuit breakers, transmission lines, fuses, and switches--that he switched on, in 1882, to serve some in the financial district of the very large New York City, despite the fact that a fully functional system that employed a water wheel was being used in the small English town of Godalming the previous year.

Source: Kruszelnicki, K. (2006). *It ain't necessarily so . . .bro*. Sydney: HarperCollins.

Making Science Lessons Engaging, More Popular, and Equitable Through Emotional Literacy

Brian Matthews and Emma Snowden
Goldsmiths College, New Cross, London, UK
b.matthews@gold.ac.uk, e.snowden@gold.ac.uk

Abstract

This article highlights the benefits of introducing aspects of emotional literacy into lessons. Data were collected from 165 Year 7 pupils in two schools over 1 year. Pupils benefit as they can enjoy science more, as well as learn to work together and support each other to learn. The research found that incorporating emotional literacy strategies into lessons on a regular basis increased pupils' interest in continuing with science as a subject, especially in the case of girls. The latter part of the article explains in detail the strategies that were used to develop pupils' emotional literacy and specifies how these can be utilised effectively so that interested teachers can replicate them.

To read the full text of this article (16 pages), please **click here**.

Demonstration

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

Understanding Dynamic Equilibrium

By: Pat Waller, 2007 President, National Association of Biology Teachers (NABT), USA
pwaller@nabt.org

Needed. Two students and a line on the floor.

Ask for 2 student volunteers. One student stands on one side of a line on the floor and the other student stands on the other side of the line, both facing the class. The line on the floor represents a membrane and the students represent molecules.

Ask 1 of the students to cross the line. As soon as that student crosses the line, the other student must move to the side of the line from which the first student came. Then ask the class to clap their hands. Each time there is a clap, the first student must move and the other student moves to the side vacated by the first student. Of course, the class begins to clap very fast and it becomes difficult to tell which student was the first. The image of constant motion to maintain correct concentrations is better understood.

Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

Running Lane

By: Vladimir D. Yegorenkov, V. N. Karazin Kharkov National University, Kharkov, Ukraine
yegorenkov@univer.kharkov.ua

I vividly remember my first trip on a train to a nearby town when I was young. When I was walking along the carriage in motion, I was afraid to lose contact with the floor, thinking that the carriage might run away from me during the time I had no contact with it (e.g., while being in the air during a jump). This preconception (wrong, of course) induced me to think over problems of relative motion and the way people perceive them.

When I became older and was in a train standing beside another train, I often found it difficult to distinguish which of the two trains was beginning to move, especially when there was no platform in the field of view. Since then, I never miss the opportunity to clarify the thinking of others, and especially children, about similar phenomena.

I witnessed another observation of this kind when my elder son was about 2 years old. While playing, he often walked along a lane and stopped from time to time, looking each time at the lane under his feet. While I did not wish to disturb him, his behaviour puzzled me. One year later, when he was a 3-year-old, I had an opportunity to ask him what he was doing when he repeatedly walked like this again. He told me that he had observed the "running" lane. At first I could not understand what he was talking about. But some time later another occasion helped me to clarify this statement. One evening, while we were travelling in a tram, we observed the sunset through the window and suddenly he asked me: "Why, when we are standing still, is the sun standing still too, but when we are riding, the sun is also riding with us?

Much later, I found an excellent outline of these problems in the appendix titled "Physics and Perception" in Bohm (1965). The author claims that a baby begins to perceive the surrounding world in the reference frame associated with himself or herself. In contrast, adults associate their reference frame with, say, buildings or other objects at rest.

Reference

Bohm, D. (1965). *The special theory of relativity*. New York: W. A. Benjamin.

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 .

Amoeba

The single cell amoeba
Must have a perfect life
Free of cares and worries
Free of worldly strife.

It doesn't have to study
Wear school uniform and hat
It has no need for money
And as for work – what's that?

I wonder if it thinks deep thoughts
Develops plans and schemes
I wonder if, fatigued at night
It dreams amoeba dreams?

Development of Humans Rap

Yo Yo check it.
See I started out as an embryo
In my mom's body I started to grow
The first three months were differentiation
Cause my head and my arms must have separation
And me mom was smart and didn't take meds
So all that bad stuff didn't go to my head
And I stayed in mom for six more months
Till I came out crying and screaming at once
Then I grew up fast and I grew up right
I ate my veggies drank milk at night
Na na na
Drank milk at night
Na na na

Its life must be serenely calm
No stress, no dreadful fears
No nightmares to disturb its rest
No need to shed salt tears.

But is life oh so perfect
In this solitary state?
Without friends and family
Bereft of a soul mate.

Wait! Science has the answer
And without much ado
Just a little concentration
It can split itself in two.

The amoeba's life is flawless
Friends created on a whim
All witty, smart and handsome
Because they're just like him!

Jack Burnham, 13 years
Australia

I wanted to be seven feet tall
So I could play basketball
But my mom was short and my dad was fat
And I ended up looking just like that
Darn that mendelian inheritance thing
Now I can't tower over Yao Ming
Na na na
Drank milk at night
Na na na
I guess the point of my story is this:
We are born who we are, regardless
Of what we want, we're just stuck.
Having tall parents is merely luck
Na na na
I drank milk at night
Na na na
Minerals and vitamins keep you strong
They help your hair grow and stay long
So eat balanced meals every day
And you'll be happy in every way!
Na na na
I drank milk at night
Na na na . . .

Kristen Tee, 15 years
Australia

Students' Alternative Conceptions

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Animal or Not?

(a) Choose which things in the following list are animals: Donkey, mosquito, tree, fish, rooster, worm, horse, mushroom, human, lion, snail, flower, monkey, beetle, mold, whale, lizard, parrot, and butterfly.

(b) Explain how you decided if something is an animal.

Comment. Biologists classify all these as animals, except the tree and flower (which are classified as plants) and the mushroom and mold (which are classified as fungi). People of all ages tend to have a much narrower view of what an animal is (e.g., a large, fury, four-legged thing that lives on land and is capable of making a noise) than scientists. For older students, the list provided to students might include organisms from all the kingdoms of life.

Teaching Techniques

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

Cell Phone Cameras

Noticing that students were already using their cell phones for calculators, Hammond and Assefa (2007) decided to ask those students with a camera in their phone to record the magnetic field patterns formed by iron filings. Delighted with the resulting images, which could readily be printed, these authors are wondering about other applications for this technology in the classroom.

Reference

Hammond, E. C., & Assefa, M. (2007). Cell phones in the classroom. *The Physics Teacher*, *45*, 312.

Using Random Numbers to Form Student Groups

Of the random number calculators at GraphPad Software (2005), the "Randomly assign subjects to groups" option may be used to randomly assign students to groups or to randomly shuffle students (e.g., student roles) within groups. The "Randomly select a subset of subjects" option may be used to select one or more students within one or more groups. This option can even be modified to select one or more groups in a class.

Reference

GraphPad Software (2005). *Random number calculators*. Retrieved December 24, 2007, from http://graphpad.com/quickcalcs/RandMenu.cfm .

Formative Assessment Techniques

The science teachers at Concord High School, New Hampshire, United States wanted to do better than the traditional teach, test, and then find deficiencies in student understanding that may never be addressed (Crumrine & Demers, 2007). Rather, they sought effective ways to continuously monitor student understanding that would allow them to respond to any deficiencies at the time, and also wanted to do better than the standard practice of class questioning, where the thinking of many students typically remains hidden. As a result of their search, they arrived at the following formative assessment techniques, each of which has both benefits and limitations:

- *Electronic response devices (or clickers)*. Requires a computer, projector, and response devices. Each student uses a response device to answer the same question simultaneously. The class results are displayed, via PowerPoint software, for instant analysis.
- *Individual whiteboards*. Each student writes his or her response to a teacher question on a 1-foot-square whiteboard and the class then holds up their boards for the teacher to view.
- *Index cards*. The teacher collects, from each student, a 3" x 5" card on which one or two questions have been answered. The cards allow more detailed responses (e.g., working) to be displayed than individual whiteboards, and may be with or without student names. This

technique may be used at any time during a lesson, and the cards may even be used as exit cards at the end of a class.

- *Student journals*. Students record questions and wonderings in their journals, which are monitored by the teacher who also provides feedback.
- *Popsicle sticks*. When the teacher does ask a question of the class as a whole, he or she may randomly choose a student to respond by drawing, from a jar, one of a set of popsicle sticks on each of which has been written a different student name.

Reference

Crumrine, T, & Demers, C. (2007). Formative assessment: redirecting the plan. *The Science Teacher*, *74*(6), 64-68.

Ideas in Brief

Ideas from key articles in reviewed publications

Field Investigations are not to be Forgotten

Most school science and high-stakes testing focuses on only the very narrow type of inquiry characterized by randomized and manipulated control group experiments, with an emphasis on testing predictions or hypotheses and cause and effect. However, Windschitl, Dvornich, Ryken, Tudor, and Koehler (2007) recognize that this does not characterize much of the science presently being carried out around the world and that scientific investigations may take many forms and need not be carried out in a laboratory, and call for increased attention in school science to three different types of field investigations; namely, descriptive studies, comparative studies, and correlative studies.

Each of these types of field investigation is characterized by a different type of research question. While a descriptive study might ask, for example, “How many?” or “How frequently?” a comparative study might ask “Is there a difference between groups or condition?” and a correlative study might ask “Is there a positive or negative relationship between two variables?” These types of field studies also tend to be sequential, with a descriptive study possibly leading to a comparative study which in turn can lead to a correlative study, and in this sense comparative studies are a bridge between descriptive and correlative studies. Because comparative studies have similarities with not only descriptive and correlative studies but also with controlled investigations, in which one variable is changed to create a controlled comparison, Windschitl et al. (2007) suggest that school curricula should place a particular emphasis on comparative studies. Since the interpretation of data in correlative studies does require an understanding of some basic statistics, this type of investigation is best left till Year 10.

Reference

Windschitl, M., Dvornich, K., Ryken, A. E., Tudor, M., & Koehler, G. (2007). A comparative model of field investigations: Aligning school science inquiry with the practices of contemporary science. *School Science and Mathematics*, *107*, 382-390.

A T-Test can Make a Science Project

Consider the common type of science project exemplified by the student who wants to study how the addition of different quantities of water might affect plant growth. Let’s say, as part of her experiment, she added 15 mL of water to a number of cups that each contained one planted seed (Set A) and 30 mL of water to each of another set of cups (Set B), with other variables being kept constant, and that after a certain time she found that the average height of the plants in Set A was 5.1 cm and for Set B it was 5.4 cm. Based on these results, the student might conclude that adding 30 mL of water is better for the growth of these plants than adding 15 mL, and it is the drawing of this type of conclusion that Gonzalez-Espada (2007) identifies as the flaw that can prevent a good project being an excellent one.

Before trying to reach such a conclusion, we must first recognize that there is some variation in the plant heights in each group and, on this basis, ask if the difference in averages is significant or whether the averages are actually sufficiently close to really represent the same result. Put another way, it is possible that the variability in the raw data is greater than the difference in the averages, indicating that although the averages appear to be different, the difference is due to chance rather than the different treatments.

A t-test (GraphPad Software, 2005), a simple on-line statistical analysis that is very user-friendly and easy to use, can resolve the issue. To use this analysis, a project needs to:

- Compare two or more groups.
- Have a minimum of 10 results for each group.
- Use numerically-measured data (as opposed to categories, even if labeled with numbers).

Using the default settings of *Enter up to 50 rows*, say, and *Unpaired t test* at GraphPad Software (2005) and entering data, one can calculate a P-value (or probability value), which gives the chance that the two averages are similar. While a P-value of ≤ 0.05, or 5%, is often recommended as the cut-off, for school project work (where the assumptions of the t-test may not be fully met) the more flexible $P \leq 0.10$, or 10%, is suggested. In short, when $P \leq 0.10$, or 10%, one can have a high degree of confidence that the difference in averages is due to treatment rather than random variation.

However, even a very low P-value is not a zero value and thus does not protect a conclusion from being challenged. Random and systematic experimental errors are always present and must not be ignored in the discussion of the findings. Other examples of student projects to which a t-test might be applied are:

- Which brand of battery lasts longer?
- Who can solve a puzzle faster: Boys or girls?
- What weight (e.g., how many coins) can different brands of paper towel hold?
- Does reaction time vary with age?

Students can appreciate the need for such a statistical analysis, and use it, without needing to understand the details of the analysis. While this approach is not recommended for more formal research (for a sample size > 30, one would use an ANOVA test with post-hoc analysis), it is fine for student projects.

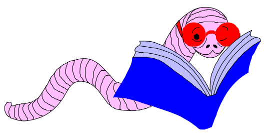
Reference

Gonzalez-Espada, W. (2007). Using simple statistics to ensure science-fair success. *Science Scope*, *30*(8), 54-58.
GraphPad Software (2005). *T test calculator*. Retrieved December 24, 2007, from http://graphpad.com/quickcalcs/ttest1.cfm .

SER *asks Wilson Gonzalez-Espada.* I'm wondering how students might become aware of the concept of a t-test? My experience is that while the idea might feature in postgraduate studies in science education, for example, primary and secondary teachers would typically be unaware of it.

Wilson. I finished my bachelor's degree in physics teaching without knowing about statistics. I was first introduced to t-tests in my first research methods course at the Masters level (in science education). Once I realized that you can compare two results to see if they are significantly different or about the same, I immediately saw an application for science fair projects. In fact, as a high school junior I completed a science fair project. The project did not advance beyond state-level competitions, partly because of the lack of statistics. If my mentor had known about statistics, many students' projects would have excelled.

I do know that the topic has been explored before and that at least one book about the subject has been written: *Using Statistics in Science Projects*, by Melanie Jacobs Krieger (ISBN 766016293). However, this book has been discontinued. Teachers interested in science fair projects can easily learn the basics of t-tests from the website I cited. Also, if their schedule allows, those enrolled in a science teacher preparation program might take a basic statistics elective.



Research in Brief

Research findings from key articles in reviewed publications

The Views of Clergy on Science and Religion

Students can resist evolution education if they feel that the ideas conflict with the tenets of their faiths. To explore such perceived conflict, Colburn and Henriques (2006) decided to study the views of some clergy on science and religion, and particularly evolution and creationism.

Creationism is not a single set of beliefs. For example:

- *Young Earth creationists* accept the Hebrew Bible (Old Testament) literally, believing in 7 literal days of creation and that the Earth is between 4000 and 10,000 years old. During this time, all life was created more or less in its present form.
- *Old Earth creationists* share many beliefs with Young Earth creationists, but believe that the earth is much older than 10,000 years. Often, each of the 7 "days" of creation is viewed as possibly spanning millions or billions of years.
- *Intelligent design supporters* generally support the idea of evolution by natural selection, but believe that some biological structures are irreducibly complex and must have been designed by some outside (e.g., supernatural or extraterrestrial) agent.

Eight mainly local (Long Beach, California, USA) and Protestant Christian clergy and 1 religious studies professor (3 women and 6 men, in all) were interviewed as a pilot for a survey and questionnaire administered to 157 clergy members of a local ecumenical council (response rate 33.8%). Even within this small sample, many positions existed, although the responses did cluster around the following categories:

- The (Christian) Bible was not meant to be interpreted literally. Doing so creates a stumbling block to accepting evolution and other scientific conclusions.
- It is difficult to move from a concrete interpretation of the Bible to a more abstract one.
- God plays a role in nature and evolution.
- It is okay to ask questions and have doubts.
- Science is limited in what it can understand.

Overall, the clergy did not see a need for conflict between evolution and their religion and felt strongly that creationism did not have a place in public school classrooms, holding a belief system that can be described as theistic evolution. In this view, there is a marriage between biological evolution and theism, which is the belief that God continues to act in, and affect, the material world.

Students need to realize that science and traditional belief systems represent different ways of knowing. For example, the concept of God is not a part of the scientific world, because science can take no position on the supernatural. Also, evolution is not something that students should be asked to believe. Rather, it is to be understood and accepted on the basis that it provides an explanation for the empirical evidence. In other words, science and religion often look at the world through different filters. Science should not be treated as dogma and religion should not be viewed as scientific endeavor. This study suggests that science educators may find clergy to be a valuable ally in addressing misconceptions about the contentious nature of science and religion.

Reference

Colburn, A., & Henriques, L. (2006). Clergy views on evolution, creationism, science, and religion. *Journal of Research in Science Teaching*, *43*, 419-442.

? ? ? ? ? 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!

Inquiry (three sets of questions)

(a) Inquiry is the rage! Everyone seems in favor of it; all curricula, texts, and reform efforts embrace it! But, why the fuss, confusion, and lack of meaning established prior to its continued use? Is there also non-scientific inquiry? In short, why the fuss about "scientific" inquiry?

To me, this seems to be a fad. Scientific methodology was established a long time ago. I don't remember Francis Bacon calling it an inquiry method.

Juan Manuel Lleras, Bogotá Children's Museum, Colombia

I have taught science in New South Wales, Australia since 1975, and am a passionate science teacher. Students enjoy my lessons because I do many exciting demonstrations and they get to do many experiments. I have lived through the Nuffield and ASEP discovery technique period, a technique that at the time seemed a good idea. I have lived through Harry Messel (my hero) and Boden and I currently suffer through outcomes-based syllabi and reference-based assessment; not to speak of the current range of boring, uninspiring textbooks produced to complement the boring and uninspiring syllabi.

As a teenager, I had a real chemistry set and used to make electrical things. I used to pull things apart to see how they work. I used to make gunpowder and mix potassium permanganate and glycerol, and spent many hours trying (unsuccessfully, I regret) to heat calcium carbonate to produce calcium oxide, which I read was exothermic when dissolved in water.

So, in a nutshell, I consider myself a real scientist who did the apprenticeship as a teenager and passed on my passion as a senior chemistry teacher and a high school science teacher. I see--wrong, we all see--what students like. When they like something, they then learn something. That includes the teacher, because if they like the teacher they look forward to lessons and want to learn.

I believe I am paid to teach. To teach science means to make lessons exciting and motivating. It means, to some extent, chalk and talk, practical activities, challenging activities, relevant games, nature walks, visits to the museum, and other excursions. Worksheets can be done at home, as can library research. I am paid for my expertise. If I want driving lessons, then the instructor takes me driving and teaches me.

Take the topic of machines, for example; something almost all students love and so will learn easily, and that is so relevant to their lives because the world is made of machines.

1. Talk about machines (not too long).
2. Show a couple of examples.
3. Give the kids machines to determine what type of machine they are (the inquiry part perhaps, or problem solving).
4. Take them to the Powerhouse Museum for a machines excursion.
5. Assess their knowledge.
6. Unit finished.

Alas, I speak to many students from many different schools, and the quality of curricula and the expertise of science teachers is very second rate and I fear that when my vintage of science teachers retire, it will require a revolution to reestablish my wonderful subject Science back to its former status and glory.

I know I did not quite answer the question, but I did give my view on exciting and motivating science teaching.

Roy Butt, Australia

I am a new graduate teacher (primary school) and I will attempt to explain what I see inquiry as being. The inquiry approach has its roots in the constructivist pedagogy and the advantages as far as I can see it are:

- It is an economical use of knowledge because the students only examine relevant facts.
- It enables students to look at the content and relate to it in a realistic way.
- It is motivating in an intrinsic way because it encourages reflection by the students, which in turn enables them to make their own decisions, which are meaningful to them.
- It develops the all important metacognitive skills in which students learn how to learn.

- The teacher becomes more of a facilitator of learning rather than being a "chalk and talk" teacher.
- It allows students to become problem solvers.

The process I use is:

1. Tuning in (or eliciting prior knowledge)
2. Deciding direction (analysis of what the problem/issue is). Usually involves some sort of prediction or hypothesis
3. Organising (selves/direction we are going to take)
4. Finding out (researching, finding the information required for the inquiry)
5. Sorting out (the data into charts, tables graphs, etc.)
6. Reflection and evaluation (what did we accomplish in our inquiry)

That is a very brief answer to your question, but I find it a fantastic basis for most units of work.

Lisa Thomas, Australia

These are incredible questions that go to the heart of science education. I don't have all the answers, and I don't expect anyone to. This query goes to the heart of what I've been working on for the last 10 years. I wish I could provide erudite answers that would completely clarify this entire arena. Instead, I'll briefly provide what little insight I've gained over the last decade. Hopefully, others will fill in the gaps, and I'll learn more too.

I learned about scientific inquiry by reading F. W. Westaway, Prof. E. H. Hall, and others. Firstly, I'd like to say that non-scientific inquiry is what most people think of when they say *inquiry*. Questions unanswerable by collecting reproducible evidence fit into this category. Asking about the magnitude of beauty of a painting or movie star would be distinctly non-scientific, because "beauty is in the eye of the beholder." Inquiring into the efficacy of aluminum foil caps to prevent the CIA from reading your mind would be non-scientific because the underlying premise--that the CIA can read minds--involves extrasensory perception whereas science is based on evidence from the use of our five normal senses only.

You'll find some variety in the definitions of scientific inquiry. It's important because the science laboratory experience should provide opportunities to do it, and science courses should have two goals; learning some basic science concepts and developing a scientific mind. According to a number of authorities, scientific inquiry best fosters the latter, and the science laboratory, properly done, provides scientific inquiry opportunities.

I personally believe, and am supported by many educators in this belief, that extensive exposure to scientific inquiry improves the thinking skills of individuals and so makes them better citizens. Carl Sagan also held a similar viewpoint, as expressed in *The Demon-Haunted World*. For more information on this topic, I can recommend *America's Lab Report* written by the National Academies.

Harry Keller, ParaComp, Inc., USA http://www.smartscience.net

In recent years, inquiry-based learning has become the basis for delivering the more formal instruction used in subjects. It is seen to be bringing together, in a multi-faceted way, the principles of the various disciplines.

Inquiry has been defined and described according to the subject area in which it is used; historical inquiry, literary inquiry, mathematical inquiry, scientific inquiry, and so on. Whatever the type of inquiry being undertaken, they all engender similar principles and procedures such as aim/focus/question, planning, research/investigation, analysis of findings, application of findings, evaluation of sources, implications of findings, and acknowledgement of sources (bibliography, etc.).

Inquiry of any type is planned and sequential in its presentation. To conduct an inquiry is to use the knowledge, skills, and resources at our disposal. Ultimately, for the student, it is to help them further their learning by creating new and deeper understanding in an area of study. Inquiry by any other name is still inquiry, no matter the subject/discipline setting. Students will need to assemble the skills from all aspects of their learning in order to capitalise on the opportunities that an inquiry process provides.

Noelene Wood, Tasmania, Australia

I distinguish between inquiry Science, the name given to a model for teaching/learning, and scientific inquiry, which is a type of inquiry. Within the inquiry Science model, an inquiry activity is one that requires students to answer a question by analyzing information themselves (Bell, Smetana, & Binns, 2005). The fuss being made about the inquiry Science model appears justified, as it can facilitate superior cognitive and affective outcomes in science education (Mao & Chang, cited in McComas, 2005; Shymansky, Kyle, & Alport, 1983; Smith, cited in McComas, 2005).

Note that, in accord with the above definition of an inquiry activity, the question, the method(s) used to collect information, and/or even the data itself may be student-generated, provided by the teacher, or a combination of both, an inquiry activity need not require the hands-on manipulation of materials, and it may also be conducted at a site beyond the classroom, such as a park, nursery, pet store, or museum. Also, in Eastwell (2006), I showed inquiry Science activities categorized according to four levels--Level 1, confirmation; Level 2, structured; Level 3, guided; and Level 4, open--depending upon which of the following is provided to students; the question, the method, and/or the conclusions.

I suggest, then, that an inquiry Science model can be said to be employed when the approach to teaching/learning has one or more higher-level inquiry activities (i.e., activities at Level 2 or above) as central components. Similarly, we have inquiry Maths, inquiry Social Science, and so on. Indeed, it may often be appropriate to use a more general term, such as inquiry education, inquiry learning, inquiry approach, or just plain inquiry to describe the teaching/learning model being used.

Inquiry Science does not necessarily equate with unguided learning, the type of learning that expects students to discover targeted concepts on their own and that restricts the role of the teacher largely to suggesting sources of information and offering alternatives. Quite the opposite is in fact the case, with an inquiry learning approach being quite compatible with guided learning/instruction, the process in which knowledge is constructed as a result of a teacher providing systematic guidance focused on the learning objectives in a setting characterized by interactions among the teacher, the phenomena, and students. (Note that here I am differentiating between guided learning/instruction and Guided Inquiry, the label given to the third of the four levels of inquiry in the inquiry Science model mentioned above. Indeed, Levels 2-4 inquiry can be implemented using varying degrees of guidance, with even Level 4 open inquiry featuring much guided learning/instruction a possibility.) The evidence is that, for novice and intermediate learners having limited prior knowledge, unguided or minimally-guided instructional approaches are less effective and less efficient for learning than guided approaches, and can even be ineffective or, worse, detrimental (de Jong, 2006; Kirschner, Sweller, & Clark, 2006; Mayer, 2004). Indeed, "after a half-century of advocacy associated with instruction using minimal guidance, it appears that there is no body of research supporting the technique (Kirschner, Sweller, & Clark, p. 83).

It may be useful to elaborate that the inquiry Science model can apply to a single activity, the treatment of a particular segment of work within a broader unit, or an extended project. In the second case, an inquiry activity might provide the exploratory phase in a 7E learning cycle approach (Eisenkraft, 2003). With an extended project, such as problem-based or design-based learning (e.g., where students might be investigating an issue of local significance that requires numerous topics to be addressed), I have found the overall, four-phase approach comprising invitation, exploration, proposing explanations and solutions, and taking action (Yager, 1991) very useful. While this also represents a learning-cycle structure that can take the form of inquiry, an extended project typically requires multiple topics to be addressed, and each of these topics may be treated in a (7E) learning cycle way, thus resulting in a nested learning cycle structure.

As an aside, while inquiry Science has much to recommend it, there are severe impediments to its implementation in many classroom situations. For example, hands-on laboratory experiences need to be an integral part of learning sequences rather than, say, restricted to Level 1 confirmatory, "add-on" exercises at the end of a unit. However, having a class timetabled into a laboratory once each fortnight, for example, does not allow for such. This is another issue, though.

While inquiry Science is a model for teaching/learning, scientific inquiry is a type of inquiry, and we can further distinguish between scientific and non-scientific inquiry. Science is only one of many different ways by which we can come to know our world (others are the aesthetic, interpersonal, intuitive, narrative, paradigmatic, formal, and practical) (Eisner, 1985). Like the other ways of knowing, the scientific way of knowing has characteristic features, including limitations. In the case of science, these features comprise what the literature commonly terms the nature of science (NOS) (see, e.g., the summary in Eastwell, 2002). So, scientific inquiry is inquiry that conforms with the NOS, and I think it is synonymous with science, defined as "the active and creative engagement of our minds with nature in an attempt to understand" (Derry, 1999, p. 304). Of course, an inquiry Science (the teaching model) approach to teaching and learning will employ scientific inquiry (i.e., science).

It appears we can be confident that the term *non-scientific inquiry* is also a legitimate term. A quick Google search on the term shows it being used widely in fields that include social science, law, and psychology, a higher-education course outline requiring students to contrast scientific inquiry with non-scientific inquiry (Gibbons, n.d.), and Philip Kitcher, a leading philosopher in the United States, having given a lecture titled *The Structure of Non-Scientific Inquiry* ("A New Lecture Series," 1995).

What, then, might non-scientific inquiry "look like." While I am no expert in the field, it seems that non-scientific inquiry must be inquiry that involves aspects outside the realm of the NOS. Consider, for example, an investigation of which brand name of a particular food product tastes best. While a scientific inquiry might use blind taste testing of a suitable population, a non-scientific inquiry might question this population as to their taste preferences. The latter is non-scientific, because scientific knowledge demands the use of empirical evidence (i.e., evidence based on experiences through sensory--as opposed to extrasensory--perception and extensions by instrumentation) and some of the evidence used in decision-making in this case could well be non-empirical (e.g., people being influenced emotionally by an advertising campaign).

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Peter Eastwell, Science Time Education, Queensland, Australia

(b) Can degrees of inquiry be identified? What is the value of such adjectives as guided, coupled, directed, full, and pure to qualify the term? Does this help or confuse what is meant? In short, why does inquiry invite/require so many adjectives?

Part of the fashion. Inquiry specialists hope to publish a book on one of the particular brands of inquiry; if possible, to obtain royalties.

Juan Manuel Lleras, Bogotá Children's Museum, Colombia

I am not familiar with all of these terms. I know of only three styles of scientific inquiry and will explain them as I understand them. Others may have different definitions. Directed scientific inquiry provides explicit quidelines (even "cookbook" procedures) for the inquiry. Full scientific inquiry provides no direction at all, except for a topic or question. I think of it as what scientists do. Guided scientific inquiry provides considerable latitude and, at the same time, limits the scope of inquiry so that students don't go too far astray. Its best implementation requires close supervision such as can only be provided in very small classes. E. H. Hall recommended that class size be limited to 12 students per teacher. The teacher also has to be well-trained in this mode of instruction and have extensive knowledge of the subject area, related topics, and the history of science appropriate to the instruction.

I think that the proliferation of adjectives comes from the range of guidance available and other stylistic variations. Under the best circumstances, students will discover not only science concepts, but also the empirical nature of scientific inquiry. They should come to appreciate random and systematic error and that answers to questions lead naturally to more questions and are never final.

Harry Keller, ParaComp, Inc., USA http://www.smartscience.net

In my foregoing part (a) response, I mentioned categorizing inquiry activities according to four levels--confirmation, structured, guided, and open--based upon which of the following is provided to students: the question, the method, and/or the conclusions. This hierarchy is useful, because it can be used to assess the degree of inquiry of an activity, suggest ways by which the inquiry level of an activity might be adjusted (even partially, thus easing the transition for students from one level to the next), design inquiry activities, and better sequence inquiry activities during a course of study (e.g., "throwing" unprepared students into a Level 4, open inquiry activity may be as unproductive, in terms of both cognitive and affective outcomes, as the other extreme of restricting their experiences to Level 1 [confirmation] activities only).

Such a hierarchy can help teachers move progressively from a more traditional science teaching approach, with a heavy--if not complete--emphasis on Level 1 inquiry, to one characterized by an appropriate amount of, and balance between, the higher levels of inquiry, and the accompanying labeling also facilitates efficient communication between educators, such as might be required in documents like syllabi and school work programs. Note, though, that the adjectives used here apply to the inquiry Science model for teaching/learning rather than to how science is done (i.e., scientific inquiry).

Peter Eastwell, Science Time Education, Queensland, Australia

(c) Why is description of the natural universe confused with science itself? What is a more complete view of what science is? Is it synonymous with inquiry? Why are science writings (including textbooks) thought to exemplify science itself? In short, why are all the results of "sciencing" thought to be science?

Science is the body of knowledge about the universe. Description is a part of science, but not all of science. Again, the rest of your question can be answered as part of a current fashion, that I hope doesn't reach Latin America, for we already have some very annoying ones.

Juan Manuel Lleras, Bogotá Children's Museum, Colombia

I think that the popular press has caused great confusion by attempting to make science understandable to the increasingly science-illiterate populace. In my view, better science instruction may help to reduce the extent of this inaccurate view of science. To me, "sciencing" is science. The results are just the concepts, theories, laws, etc. of the natural universe.

It's as though people confused the automobile assembly process in a factory with the automobiles themselves. Explaining the science process requires much more effort than just stating the outcomes.

Harry Keller, ParaComp, Inc., USA http://www.smartscience.net

As I said in my part (a) response, I think science may be considered synonymous with scientific inquiry. Further, when science (the active and creative engagement of our minds with nature in an attempt to understand) is being done, practitioners have been found to engage in 10 activities that comprise the Activity Model for Scientific Inquiry (Harwood, 2004); namely, asking questions, observing, defining the problem, forming the question, investigating the known, articulating the expectation, carrying out the study, examining the results, reflecting on the findings, and communicating with others. During this process, scientists engage in as many of these activities, and in whatever order, as is needed. The results of science, then, are a part of science; but a part only. For example, when aiming to answer a question, a researcher might use resources such as journals, books, the World Wide Web, and/or experts to find what has been done before and is already known in the area (i.e., they are “investigating the known”), and such retrieved knowledge--knowledge that is the result of “communicating with others”--represents the results of science.

It does appear, though, that in some educational contexts the results of science are unfortunately being given an inappropriately high weighting. Perhaps one reason for this stems from a desire by teachers to best prepare students for “the next level,” but this thinking appears to have severe limitations. Does primary science content boost a student’s lower-secondary science achievement? I think not. Does lower secondary science content boost a student’s higher-secondary science achievement? I think not, although appropriate mathematical skills are a pre-requisite. In fact, even taking a high school physics course has only a modest impact on achievement in introductory college and university physics courses, with institutions that restrict students without high school physics from enrolment in certain undergraduate courses being asked to rethink that policy, since academically stronger students with calculus can do as well as, or even better than, students who have taken physics (Sadler & Tai, 1997, 2001).

Also, courses that focus heavily on the transmission and retrieval of content can be implemented with far less effort and, in the case of introductory university science courses with large enrolments, for example, might even be necessary from a management perspective. Ideally, science textbooks, classrooms practices, and assessment, for example, should portray the aspects of science (i.e., scientific inquiry) in an appropriately balanced way in the broadest sense, and this will include representation of all activities comprising the Activity Model for Scientific Inquiry.

Perhaps a source of confusion associated with the use of terminology stems from failing to recognize the distinction between inquiry Science (a model for teaching/learning science) and scientific inquiry (a type of inquiry). Consider this example. Adopting the definition of an inquiry activity, as used in the inquiry Science model and provided in my part (a) response (i.e., an activity that requires students to answer a question by analyzing information themselves), we would conclude from the Activity Model for Scientific Inquiry that science (i.e., scientific inquiry) involves more than an inquiry activity. However, such reasoning is meaningless and pointless, because it involves the transfer of the definition of the term *inquiry activity*, for the purposes of a teaching model, to the different domain of how scientific inquiry is done, for which the definition is not intended.

Designing a quality science education program. While thinking about these issues, allow me to conclude by sharing a couple of considerations for designing a quality science education program. First, we should not confuse the way a novice best learns in a discipline (i.e., the pedagogy) with the way an expert works in the discipline (i.e., the methods and processes, or epistemology), so unguided learning/instruction is not recommended. (See evidence in my part [a] response.) However, while it might not be a priority for scheduled science classes, I think unguided learning can still play a useful role in a school’s curriculum by, for example, being an approach adopted by students who choose to join a science club and undertake a project, perhaps even for entry in a school science competition.

Second, there are many worthwhile non-inquiry science activities (e.g., retrieving information from a library, concept mapping, and constructing a scale model). Like inquiry learning, these activities can also be implemented with varying degrees of guidance, and may even play a role within an inquiry learning sequence (e.g., there are multiple opportunities for using concept mapping within a 7E learning cycle). So, we should also not place too great an emphasis on inquiry to the extent that we think, say, that every science lesson must be an inquiry lesson.

Finally, while inquiry learning (as described earlier) is desirable, it does require more time than traditional learning approaches, thus reducing course content, and a trade-off between depth and breadth (or quality and quantity) is required. To achieve this, we might first identify those concepts/topics for which a deep understanding of the concepts is desired and use inquiry learning (involving the 7E learning cycle and emphasizing the processes involved in doing science) to teach for conceptual knowledge and understanding. However, for some things, a deep understanding is not necessary. For example, as Zirbel (2006) observed, to drive a car, all most of us need is a working knowledge of the process and training in how to drive, rather than a deep understanding of what happens inside the engine. So, for those other topics that can be covered more superficially, direct instruction and practice (representing the transmission model for learning) still have a place for sharing factual and procedural knowledge. Lecture, for example, is very useful to convey large amounts of knowledge in small chunks of time. The key for educators, then, is balance; striving to achieve an appropriate balance, in science education courses, across all aspects of science and the teaching and learning of it. The concept map of Figure 1 which, in addition to what has already been mentioned, includes the Inquiry Classroom Management Checklist (Sampson, 2004), may provide a useful summary of aspects of inquiry Science.

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Peter Eastwell, Science Time Education, Queensland, Australia

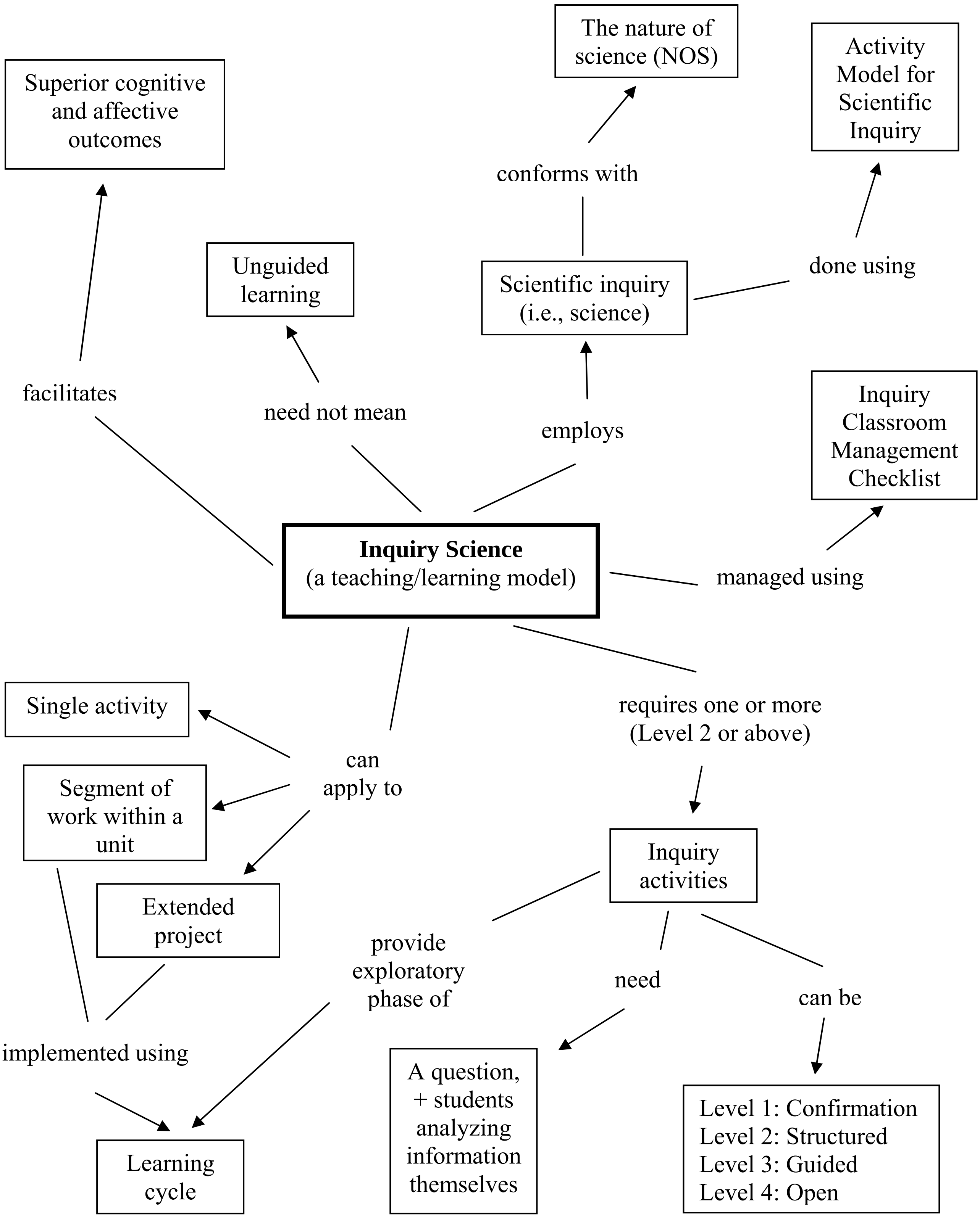

Figure 1. Overview of the inquiry Science model.

A More General Response to all Questions

Your agent provocateur is too transparent. The question to be asked is about learning. Constructivism is how science and mathematics is learnt for understanding. However, most of the science and mathematics in schools is about selection--natural selection, if you like--so the process of learning is not so important when there is a large enough population to self-select from.

However, the science/maths student is becoming an endangered species and the process by which learning takes place--maturation if you like--becomes very important! Many so-called science teachers are part of the selection process; teach to the test rather than teach for understanding, no time!!! This is a universal issue that fashions of teaching methods, such as problem-based learning, habits of mind, and inquiry-based learning, conveniently avoid.

Why bother? Who cares? School teachers do care, but university selection processes care for performance without the investment in the process. Science/maths student extinction is on the horizon, as is the shortage of science/maths teachers who wish to perpetuate this system. There are plenty of physics teachers; just not enough who want to teach physics. Check how many administrators and e-learning leaders are physics trained, yet not teaching physics--in all systems in every country.

My two cents worth, for what it’s worth. The question? Not quite a complete waste of time, but a fair approximation!

Gary Bass, Australia

Reply by the Question-Asker, Robert E. Yager, USA

The Centrality of Inquiry to Reforms in Science Education

My three questions stimulated many responses, some clarifying alternative views, some objecting to the idea, some adding perspectives, and one indicating the questions were “not quite a complete waste of time.” Some responses referred to such terms as “presenting instruments,” “delivering instructions,” and “providing questions,” some suggested that students and teachers should design activities, others proposed specific discipline structures for facilitating understanding and criteria for selecting content, and some focused on student performances and the importance of motivating teacher demonstrations. All in all, the questions, perceptions, and interpretations were fair and informative, while at the same time providing indicators of continuing problems with the term *inquiry*. Many can be described as very teacher-centered. The responses also indicate the need for clarity and focus. Linguists agree that no term is of value until first its meaning has been established and that there is a reason for its use (i.e., the technical term is a short-cut to a more complex meaning that would require many words). All responses indicate the importance of dialogue, which is the purpose of this communication venue.

I am pleased to “come out of hiding” and to offer an analysis of the problem and the dialogue, while sharing my own experiences and reasons for raising the questions. I retired last year after 50 years as a professor of science education that includes 16 years as Head of Science at our laboratory school. All of my research preparation (M.S. & PhD) was in Plant Physiology. But, I have learned science education from 130 doctoral students who completed dissertations under my guidance. They know me as an enthusiast for the Michelangelo quote: “I am still learning.” One of my concerns is that too many quit learning as soon as they leave formal education, taking only the understandings instructors have given them--often with little thinking or use--and based solely on what they were told and their own experiences with so-called laboratories where almost always the answer was known prior to following the laboratory procedures!

In working with teachers as students, I soon learned that too often we want answers; sometimes even before there are questions. We are so sure that our students need what we want to give them! Our lessons are for them to receive. I am amazed as I read the reactions to my questions and the responses that illustrate what we all are too quick to offer. Once I had a teacher who was a part of a staff team promoting more reform teaching. He volunteered to outline the steps of the acts of teaching that he thought I was suggesting (hopefully using!). As one of the class leaders, he had a "Eureka," and proceeded to give a mini-lecture on what he felt I was suggesting. His was a step-wise interpretation of what I was all about. It resembled the 5E or 7E lists. The list was accurate, but was it understood by all the others once it was offered? To me we need to be more cautious in quickly providing our interpretation, assuming that such verbiage offered is a clarification and is a chance for all to have the same "Eureka." Would it not be better to invite interpretations from all and to encourage discussion of the differences, similarities, and uses in varying contexts?

I argue that such lists offered by teachers do not invite thinking and trial, but rather represent recipes for people to follow with little or no real thought. They make it easy for students to follow the science processes with no real effort or personal thinking or reason.

My activities with curriculum development projects during the 1960s and with major professional development efforts have been extensive, and include 150 federally-funded projects. The Iowa Chautauqua, which annually enrolls teachers in 3- to 4-week summer workshops at as many as five centers and includes follow-up activities offered at the same sites for 3 or more years, has been offered since 1982. Iowa Chautauqua continues in Iowa, and has moved to other states. These efforts with teachers and schools have provided opportunities for learning and the involvement of 130 PhD students over the 5 decades. More than 50 years ago I was struck with Joe Schwab's (1963) efforts with enquiry (spelling it with an *e* to capture more interest!) and the "alphabet" programs in the United States, 1960-80. I was impressed with Zacharias (1956) and the PSSC Course he developed--the first of our post-Sputnik reforms! When asked about the goal for the new course, he responded that it was merely to portray science "as it is known by scientists." He said nothing about inquiry! But, nonetheless, inquiry was perceived as important and central by many and something that scientists do.

Science: A Process Approach (SAPA) (American Association for the Advancement of Science [AAAS], 1968) was a well-known K-6 program where inquiry was the focus. It basically consisted of fourteen process skills with no other context other than they were "the" skills used by scientists. Therefore, they were important to learn--one by one! They also resulted in students "doing" them, again often without thought or ability to use them in other contexts.

Other Foci: Enlarging the 2-Dimensional Views of Science (Concepts and Processes)

Several reform efforts over the past half century have considered the history and philosophy of science. However, none resulted in many changes other than defining a curriculum and expecting teachers to use it. It was often portrayed as exhibiting inquiry. At times, scientists and science educators seized the opportunity to define the human activity called science. One of the most influential scientists in the United States was G. G. Simpson (1963), who proclaimed science to be "the exploration of the material universe with attempts to explain the objects and events encountered" (p. 81). Many use these attributes to identify the precise aspects of the activities characterizing the explorations proposed and the evidence produced and/or available to support the possible explanations offered. This sequence is sometimes characterized with the following five steps:

1. formulating questions about the objects and events found/observed in the natural world;
2. offering explanations for the objects and events encountered (hypotheses formation);
3. testing for the validity of explanations offered;
4. communicating the results to others; and
5. confirming that the results are compatible with "established" views.

These features of science also define the major aspects of inquiry! Some argue that the results are more important if the results can be used in new contexts and by other people.

There have been attempts to move beyond science as known and practiced by scientists. There have been attempts to unite science with the field of technology--after the efforts in the late 1950s and early 1960s to remove technology and relegate it to the shop and designate it as appropriate for non-college bound students. But newer programs have tried to reverse this and recognize that technology--that is, focus on the design world--is seen as more interesting, useful, and product-oriented than pure science by most people. The major difference between science and technology is that one has to accept the natural world as it is found. When it comes to technology, though, the answer is always known, as we use phenomena and explanations from the natural world (science) to develop devices seen as useful to human existence. The difference remains, but the domains and activities characterizing both are intertwined, and in some ways schools do a disservice to treat them as separate.

The National Science Education Standards in the United States

During the 1990s, there was great interest in the United States to develop National Standards. Education is not mentioned in our US Constitution, which means that the 50 states are in charge of education. But in 1987, the National Council of Teachers of Mathematics decided to develop Standards for the profession (NCTM, 1989). This was done with no government support. However, the mathematics educators were so successful that such Standards were recommended by the federal government for all curricular areas.

In science, there was a debate between the American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA). Both insisted they were already underway with Standards with the AAAS Project 2061 (AAAS, 1993) and the NSTA SS&C project. This controversy ended with selection of the National Research Council (NRC) of the National Academy of Science as the leader for developing the National Science Education Standards (NSES). The Standards resulted in an expenditure of $7 million dollars over a 4-year period, with the final version published in 1996. Two important publications following the publication of the Standards were *How People Learn* (NRC, 2000a), a review of the "learning" research, and *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000b), a book matching the size of the initial Standards book focusing only on inquiry illustrating its centrality to science and science teaching.

Table 1, reproduced from NRC (2000b, p. 29), offers a fine view of the essential features of inquiry and its variations, and helps to explain the frequent problems with the term. The list of essential features duplicates almost exactly the list of features of science itself elaborated earlier, and I like to call this full inquiry. This is perhaps redundant, but it forces a focus on the importance of requiring teachers and students to experience all five features that define inquiry in school science.

Table 1
Essential Features of Classroom Inquiry and Their Variations

Essential feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanation to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication
	More ------------------- Amount of learner self-direction -------------------- Less			
	Less -------------- Amount of direction from teacher or material --------------- More			

The variations of inquiry listed for each feature in Table 1 is where debates occur. The first, or left-most, column of variations represents what we all should strive to attain. All five features in this column indicate that the learner should "do" each feature of inquiry. The problem is the various ways guided inquiry indicated in the other three columns actually plays out with different teachers.

Unfortunately, few classrooms get beyond guided, with teachers instead often continuing to prescribe what terms students should use, what labs should be performed, and how students are expected to parrot back answers to teachers or repeat textbook explanations (and using recall assessments to define successful learning).

It seems to me that we can ignore spelling enquiry with an *e*. Webster's dictionary just defines it as "a variant of inquiry." But, inquiry has a very simple definition which is largely ignored by science educators who are enamored with it as a technical term associated with science. Webster defines inquiry as "asking about something" or merely "to ask a question." This to me sounds very much the same as both the first feature of science in Table 1 and the first goal of science teaching identified in the National Standards (NRC, 1996, p. 13). It means learners questioning--not teachers doing it for them! Inquiry is simply defined as “a search for truth or understanding” or “questioning in order to get information.” I prefer to leave it at that!

Debates About the Use of Inquiry and its Meaning

My question is how questioning and curiosity can be related to what some refer to as inquiry levels. I wonder about confirmational, structured, coupled, and guided inquiries. These adjectives suggest teacher centeredness and the view that learning can be transferred from teacher to student directly--or, that teachers need to help students develop questions and to encourage curiosity. Do we need crutches to help students question and to be curious? Most have these abilities before they begin formal schooling!

Paul Hurd (1978), one of the most prolific and informed science educators in the United States, caused quite a stir when he offered the following statement about inquiry:

> The development of inquiry skills as a major goal of instruction in science appears to have had only a minimal effect on secondary school teaching. The rhetoric about inquiry and process teaching greatly exceeds both the research on the subject and the classroom practice. The validity of the inquiry goal itself could profit from more scholarly interchange and confrontation even if it is simply to recognize that science is not totally confined to logical processes and data-gathering. (p. 62)

But, inquiry remains central to the United States NSES. But, it is both a form of content as well as an instructional tool. It is central to every state framework, to every standard textbook series, to every funded reform project. It is the “religious” nature of the term and its varied uses and interpretations that prompted my questions. Inquiry is a technical word used by experts as a short-cut for describing the whole process. However, it has become something to “believe” in; something that must be used without real concern for its meaning. Most science education researchers distinguish between an inquiry activity and use of the term *inquiry* as a learning model. Some are willing to define inquiry as the use of the 14 process skills of the SAPA program of the 1960s (AAAS, 1968). The NSES use the term to define what persons do when they engage in research, as well as one of the facets of science content that should be approached in teaching. However, most teachers do not establish, or even consider, such meanings before using the term.

After 4 years (1992-96) of serious debate about science education reform and inquiry, the Standards were released. They have made an impact, but not as great an impact as one would expect from the funds spent and time it took to reach consensus. The Standards do provide goals that frame Pre-K through Grade 12 science. The first goal replaced one advanced as an important one over 3 decades earlier in a huge National Science Foundation (NSF) sponsored effort called Project Synthesis (Harms & Yager, 1981). It was called science for academic preparation for the further study of science. It was found that it was the only one the teachers and schools considered when they prepared a curriculum and chose a textbook. The stated goals for science in the Standards were introduced first by what I call inquiry and completely omitted academic preparation as a goal. Of further interest is the fact that inquiry also became the first form of content at every level and for all eight facets of content. This inquiry goal indicates that PreK-12 science should educate students who are able to:

1. experience the richness and excitement of knowing about and understanding the natural world.

The other three NSES goals are producing students who are able to:

2. use appropriate scientific processes and principles in making personal decisions;
3. engage intelligently in public discourse and debate about matters of scientific and technological concern; and
4. increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers. (NRC, 1996, p. 13)

These three are the same as the ones listed in the Project Synthesis research.

Specific Contrasts Between Traditional and Reform Teaching That Emphasize Inquiry

The NSES begin first with visions of changing teaching. Interestingly, there was no disagreement as to how teaching should change. The Standards included a Summary Section for each section that identifies less emphasis conditions and needed changes (the More Emphasis conditions). These provide the reform visions elaborated in each section of the NSES. In the case of teaching, these are shown in Table 2.

Table 2
Reform Visions for Teaching

Less emphasis	More emphasis
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiries
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding (and involving students in the process)
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

If teaching were to change in these ways, it would certainly lead to a better understanding and use of the term inquiry. The nine recommended teaching features could be used as one way of looking at full inquiry!

The second part of the NSES calls for changes in professional development programs. These are ways teachers should continue to grow and change, as shown in Table 3.

Table 3
Reform Visions for Professional Development

Less emphasis	More emphasis
Transmission of teaching knowledge and skills by lectures	Inquiry into teaching and learning
Learning science by lecture and reading	Learning science through knowledge
Separation of science and teaching knowledge	Integration of science and teaching knowledge
Individual learning	Collegial and collaborative learning
Fragmented, one-shot sessions	Long-term coherent plans
Courses and workshops	A variety of continuing professional development activities
Reliance on external expertise	Mix of internal and external expertise
Staff developers as educators	Staff developers as facilitators, consultants, and planners
Teacher as technician	Teachers as intellectual, reflective practitioner
Teacher as consumer of knowledge about teaching	Teacher as producer of knowledge about teaching
Teacher as follower	Teacher as leader
Teacher as an individual based in a classroom	Teacher as a member of a collegial professional community
Teacher as target of change	Teacher as source and facilitator of change

Once more, changes in how teachers are treated and encouraged to change and to collect evidence of the effectiveness of the changes would result in more teacher inquirers and better examples of full and open inquiry.

The third call for change in the United States NSES is in the area of assessment. These include a focus on Wiggins' and McTighe's (1998) book, *Understanding by Design*. The contrasts are shown in Table 4.

Again, it is apparent that students need to be empowered to do real science. A fundamental part of this is assessing their own understanding. This means being inquirers concerning their own ideas and never viewing science as art, a poem, or other creative endeavor that is the sole interpretation of the person engaged. Science is a community activity subject to change, interpretation, evidence collection, and argument. Perhaps that is the point of inquiry about the term inquiry and how it is used and what it means in science education.

The NSES includes similar listings of how inquiry is content as well as a way of teaching and learning (NRC, 1996, p. 113). There are 17 contrasts between the less and more emphasis facets of the "content" of inquiry (e.g., less emphasis on covering many science topics and more emphasis on studying a few fundamental science concepts; less emphasis on private communication of student ideas and conclusions to teacher and more emphasis on public communication of student ideas and work to classmates). All of these exemplify factors that should be reviewed, analyzed, and debated if such content becomes a major component of science courses.

Table 4
Reform Visions for Assessment

Less emphasis	More emphasis
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well-structured knowledge
Assessing scientific knowledge	Assessing scientific understanding and reasoning
Assessing to learn what students do not know	Assessing to learn what students do understand
Assessing only achievement	Assessing achievement and opportunities to learn
End of term assessments by teachers	Students engaged in ongoing assessments of their work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments

Examples of Science as Inquiry

NSTA now publishes Exemplary Science Programs (ESP) monographs, each of which provides 15 examples of how schools and teachers have implemented the Standards and used the focus upon inquiry to define "reform." One of the major features of the ESP Monographs is that they include evidence of the success of inquiry teaching and a variety of ways inquiry can be interpreted and used by students. The needed changes in teaching were included earlier and represent what we mean by inquiry teaching. The Monographs now available include:

- Exemplary Science in Grades 9-12; Standards-Based Success Stories
- Exemplary Science in Grades 5-8; Standards-Based Success Stories
- Exemplary Science in Grades PreK-4; Standards-Based Success Stories
- Exemplary Science, Best Practices in Professional Development
- Exemplary Science in Informal Science Education; Standards-Based Success Stories

Others planned over the next 4 years include one for each of the NSES goals; namely, science as:

- Inquiry (with a focus on full and/or open)
- Affecting daily living
- A means for resolving societal issues
- Possible careers and improvement on economic productivity

Looking Again at the Questions, Responses, and Features Needed

Certainly there is nothing wrong with defining levels, or variations, of inquiry. But, my fear is that too many will never go beyond the last two columns of the NRC chart of Figure 1 and will remain teacher and/or curriculum centered! Instead of being "guides" for many, teachers will remain dictators and determiners of what is taught as if teachers can transmit what they know directly to students. Students may never regain the curiosity that they had prior to school.

Paul Brandwein (1983) once said that most students never experience real science even once during their 13 years of schooling in the United States. Can we consider confirmational, structured , and even guided inquiries as illustrating the acts of science for individual students? Why not call for a full inquiry experience, whether for a week or one for each grading period each year a student is in school? Would this move us to a major revolution (real reform) in school science? Should we be advocating more focus on inquiry in the teaching of college courses in which future teachers are enrolled?

Can we wait until 2061 (the AAAS reform that requires 65 years) before expecting real reforms in education? Is it not important for the citizens of every nation to improve in all four goal areas as found in the United States NSES?

Carl Sagan (1998) has written that everyone starts out as a scientist; full of questions about the objects and events around them. A uniqueness of humans is not only curiosity, but the desire to satisfy it. All humans do it; poets, musicians, artists, and religious leaders. And, of course, scientists do it too! But the uniqueness is that in science every proposed answer/explanation must be accompanied by evidence concerning its validity. The evidence must be used to convince others (the science establishment) that it indeed is an accurate explanation. Then the information can be used and becomes a part of the framework for the inquirer.

All students come to places called schools with these experiences. Perhaps too many are willing to believe teachers, parents, grandparents, or friends for satisfying their curiosities too quickly, or without questioning and evidence of the answers they offer. In schools, teachers are always right! But, why do schools not take advantage of curiosities, personal explanations, and use of them to illustrate science itself? Instead, we tend to give our students the explanations and language used by professionals. We are trapped into being transmitters of the known and fail to approach dealing with the unknown. We tend to short-cut the process of science itself. We are poor at collecting our own evidence of the validity of personally offered ideas. I am struck by friends who joke that they are saddened because they are less intelligent today than they were yesterday, because they just found out that two things they thought were valid yesterday were indeed wrong. I am also struck by teachers who are convinced of their own successes (where previous teachers have failed!). They give testimony to their own successes, and some were illustrated by the responses to my initial questions, where this analysis began!

Do we really need to expand on the dictionary definition for inquiry? Do we need to do more than to encourage our students to question, to explore, and to provide evidence for the validity of the explanations offered, and to share the evidence and thinking with others? Do we all understand science as a form of personal inquiry? Has my analysis been an analysis or a platform for raising more questions?

Feynman (1985) has written that science consists of persons called scientists dealing with three foci; namely, the things we know we don't know (this is where most practicing scientists work), the things we know that are not so (often very difficult to identify), and the things that we do not even know that we don't know (an impossibility). Perhaps this is a view of science that science educators should consider more. Instead, we want to teach students to follow directions (directly or guided) or to "confirm" what they are told or read about to be true. Are we good models of inquiry in our own views of teaching? Should we profess less and participate more in questioning, explaining, and testing such explanations for validity? Why do we leave our students with fewer questions after our instruction than before our science experiences begin? Why do we not care more about the fact that students are less curious after instruction than before and have more negative views of science, science classes, and science teachers? Let's continue to listen, to encourage, and to support thinking and curiosity which characterize inquiry and science itself. Perhaps one of the problems is that too few science teachers have even had a full experience with science themselves!

I end with many questions and my own wish list. This does not negate others and their attempts to provide more valid experiences with science in their courses. I have no problem with the NRC inquiry chart of Table 1, although I fear it can easily be misused in terms of emphasizing the essential features and never advancing beyond the strict teacher control characterizing the right hand column! Let's not repeat what has already been done! But, too, let us not fall into the trap of thinking we know more than we do about science and science learning!

In one sense, inquiry can be used as a synonym for science. Both include starting with questions, collecting evidence concerning explanations offered, and arguing with others about the validity of the explanations. Science is a continuing quest for better understanding of the natural universe. This quest is inquiry!

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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.

#3 of 40. *Develop a Safety Orientation Program*

All new employees, students, faculty, and staff should receive a specially-designed indoctrination to your safety program. This orientation should cover the philosophy, policies, and procedures. It should explain how to deal with emergencies and how to handle emergency equipment. The new person should receive a set of rules or operating manual for the academic institution or company and be expected to sign a statement (a rules agreement) indicating that they have read, understood, and agreed to follow it and realize that failure to do so can result in termination.

When I started working for the Dow Chemical Company, my orientation took 8 hours. I learned more about health and safety on that first day at Dow than I had in my prior 25 years in school. I've asked over 50,000 scientists and science educators whether they received a New Employee Safety Orientation from their immediate supervisor on Day 1, and only 5% have said "yes." I believe that pound-for-pound and dollar-for-dollar, the new employee safety orientation is one of the most important components in a safety program. And, you can't argue that it costs too much, as no purchase order or requisition is required.

Some schools require new students to have a 3-day orientation program and then score 100% on a test before they can begin attending classes. One college in Minnesota turned the first five labs in general chemistry into a 15-hour, one-credit, lab safety course. National Research Council (1995) is used as the class text. There's a final. Students have three chances to pass the final. If they don't pass, they are done with science labs for that semester.

If you are involved in hiring new employees, consider asking the candidates: "What is there in your background that suggests that you are both concerned and knowledgeable about issues of laboratory safety?" You'll never have the special opportunity again that you have on Day 1 to make a lasting impression about how much you care about health and safety.

Want to start your New Employee Safety Orientation sooner? Add the two words "Safety Conscious" to your display ad looking for new lab employees. Why not tell the whole world that your organization wants safety conscious, and not safety unconscious, employees.

Do you have a good safety orientation program? Tell us about it and we'll share your success. A sample, 1-page *New Employee Safety Orientation Checklist* is available via our website (address above).

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Further Useful Resources

Glossopedia (http://www.globio.org/glossopedia/) A website for 7- to 12-year-olds, with articles that contain text, photo galleries, video clips, audio files (e.g., vocabulary pronunciation guides and recorded animal sounds), maps, interactive features, and content-related vocabulary lessons.

Low-Cost Labs The following websites provide science lesson plans for labs that use inexpensive materials:

TeachersFirst.com http://www.teachersfirst.com/matrix.htm
Discovery Education http://school.discovery.com/lessonplans/physci.html
HotChalk's LessonPlansPage.com http://www.lessonplanspage.com/science.htm
goENC.com http://www.goenc.com/
The Educator's Reference Desk http://www.eduref.org/cgi-bin/lessons.cgi/Science
Academy Curricular Exchange http://ofcn.org/cyber.serv/academy/ace/sci/high.html
Science Lesson Plans and Resources http://cloudnet.com/~edrbsass/edsci.htm#biology
Access Excellence http://www.accessexcellence.org/AE/AEC/AEF/

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