? ? ? ? ? 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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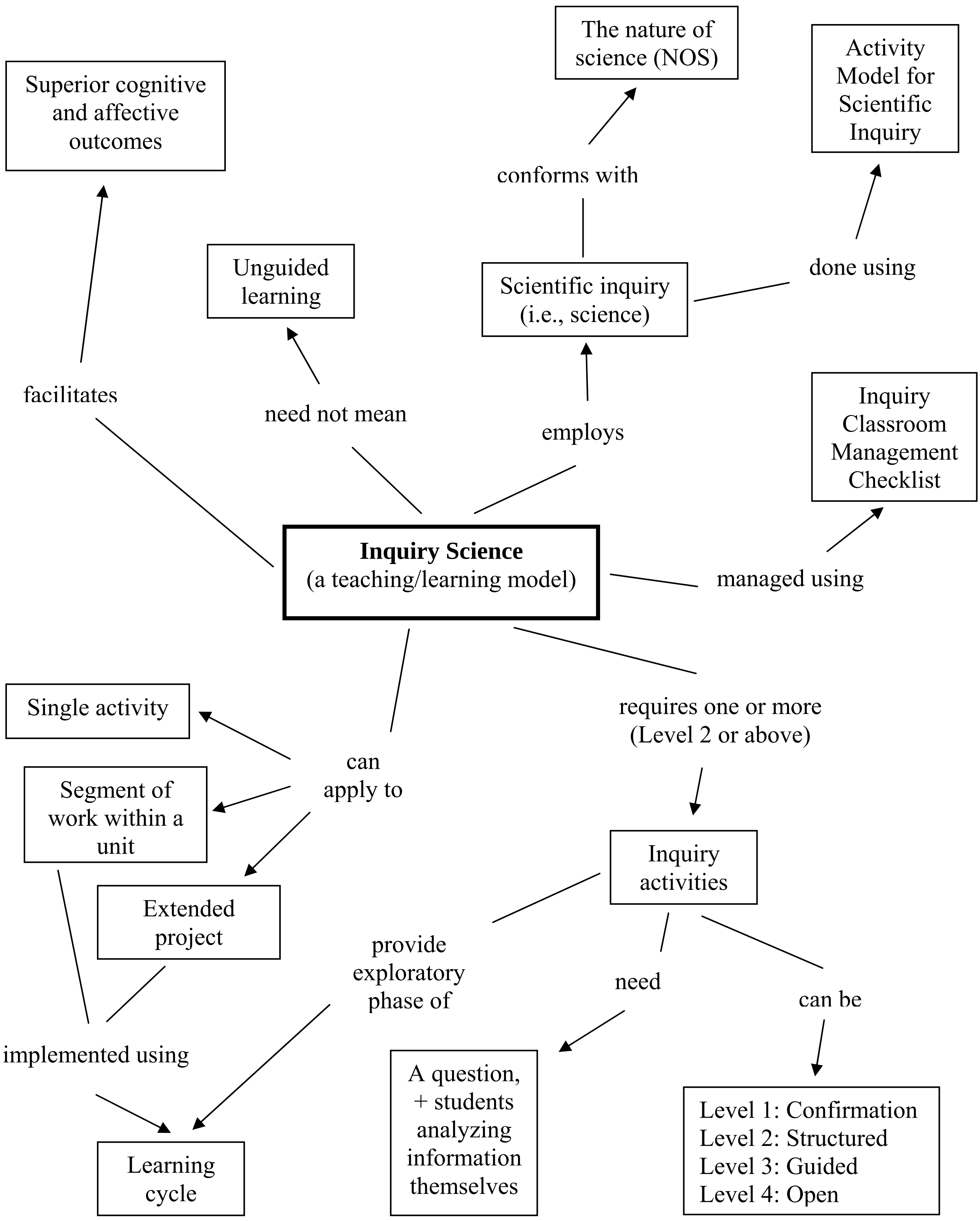

Figure 1. Overview of the inquiry Science model.

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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Readers' Forum

More on Inquiry

I'm enjoying deliberating over Robert Yager's questions about inquiry, the responses to them from readers (which included my response), and Robert's reply that appeared together in the last issue ("Your Questions Answered," 2007), as it is providing me with an opportunity to clarify and further refine my thinking. In what follows, I aim to continue the discussion by sharing my thoughts on the following issues: Confusion surrounding the use of terminology, misinterpretations concerning both the use of different levels of inquiry and reform visions for science education, distinguishing between the 7E learning cycle and inquiry, and differences that might apply to how inquiry is implemented at different stages of education. I then conclude with a question of my own.

The criteria for inquiry. While a dictionary might define inquiry as to ask a question, this criterion is insufficient for defining inquiry in the context of science education, as the essential features of classroom inquiry shown in Table 1 of Yager's reply ("Your Questions Answered," 2007, p. 107) show. I previously shared the idea that to be doing inquiry science, students need to be engaged in answering a question by analyzing information themselves. I tend to take it for granted that if students are analyzing information, they will also be drawing conclusions from their analyses (which includes making connections with scientific knowledge) and be prepared to justify these conclusions, as this is standard practice in science research proper and also good classroom practice. I find this definition of inquiry to be a satisfying one. Note also that it precludes, for example, the retrieval of information from a library from being regarded an inquiry activity, because although students might be answering a question, they are not analyzing information.

The degree of inquiry. I do not find the notion of the degree of inquiry, determined on the basis of how many of the essential features of classroom inquiry provided in Table 1 of Yager's reply ("Your Questions Answered," 2007, p.107) are involved, to be a useful one. For me, students are either doing inquiry (i.e., answering a question by analyzing information themselves) or they are not. So, I suggest we would do well to delete terms like *full inquiry*, *pure inquiry*, and *partial inquiry* from our vocabulary.

Distinguishing between degree of direction and degree of guidance. I previously referred to the literature categorizing inquiry Science activities according to four levels--Level 1, confirmation; Level 2, structured; Level 3, guided; and Level 4, open--according to which of the following are provided to students; the question, the method, and/or the conclusions. This hierarchy can be viewed in terms of the degree, or amount, of direction provided to students, with the movement from Level 1 to 4 corresponding with a movement from more-directed to less-directed inquiry (or, if you like, from teacher-directed to student-directed inquiry, from closed to open inquiry, or from passive to active learning).

However, I think we need to distinguish between such a degree of direction and the degree, or amount, of guidance provided to students. I previously also provided evidence for why unguided, or minimally-guided, instructional approaches can be considered poor pedagogy with novice and intermediate learners having limited prior knowledge. Those references conclude that unguided learning:

- Does not guarantee meaningful learning (i.e., a change in long-term memory).
- May result in incomplete/disorganized knowledge and misconceptions.

- May cause working memory overload, which in turn may prevent novices integrating all information, leading to poorer learning outcomes.
- May lose and frustrate students.

Students need to be able to benefit from the expertise of their teachers, and this is surely why we devote so many resources to making structures like schools accessible to them. What is more, teachers can, and should, provide guidance to students--as opposed to directing them--at all stages of the inquiry process and at all levels of inquiry. For example, even in the case of open inquiry, where students are investigating their own question, the teacher should support them in ensuring that their questions are suitable--even the best--ones, not by telling them what their question should be but by probing with questions that facilitate students refining the questions they plan to investigate. We probably don't actually need words to describe each level of inquiry, but if we do wish to use such, I now therefore think it follows that Level 3 inquiry would be better termed *directed* rather than *guided*. An analogy for unguided learning might be the scenario of a person enrolling for driving lessons only to find that the proposed role of the instructor is to involve little more than pointing him or her in the direction of a car that has been serviced and is ready to use and showing where the keys are kept!

The need for different levels of inquiry. Returning to Table 1 of Yager's reply ("Your Questions Answered," 2007, p. 107), Robert is rightly concerned that we might misuse this table by never moving past the right-hand column of variations. The content of this column represents the transmission model of learning, a model with widely-accepted limitations that has also been overused. However, with respect, I think he is being at least potentially misleading, if not wrong, in advising that the first column of variations is "what we all should strive to attain" ("Your Questions Answered," 2007, p. 107) and wrong in concluding that inquiry "means learners questioning--not teachers doing it for them!"(p.108), because these tend to convey the impression that the only form of valuable inquiry is open inquiry. As Brown, Abell, and Demir (2006) have recently concluded, this open view of inquiry is an incomplete one that is also the overriding constraint to college science faculty members considering inquiry-based approaches, because it can be time-consuming, unstructured, and difficult to implement both with class sizes of 20-200 students and when students lack the required knowledge and skills. I think that many primary and high school teachers likely share this inadequate view of inquiry.

Inquiry can involve students asking their own questions, but it can also include teachers supplying questions for them. In fact, from my experience, a teacher can actually "engineer" a situation to arrive at a point where students are wanting to ask a question that the teacher--or education system, through the syllabus, should I say--has already decided should be answered! I think a curriculum based solely on students answering their own questions would be unsatisfactory. Rather, I think that offering different levels of inquiry, balanced in an appropriate way, is essential during a course of study. Inquiry also need not require the hands-on manipulation of materials, can be done in a large-group lecture situation, and can even be done using data supplied by the teacher. For example, an investigation into whale migration patterns does not need to require classes around the world traveling to the ocean, catching a whale, fitting it with a transmitter, and then monitoring its movements, because such an inquiry can be readily accomplished using data available on the World Wide Web. The secret, then, is in striking an appropriate balance between all levels of inquiry, and in this way inquiry can best contribute to promoting an understanding of scientific concepts and the nature of science and developing inquiry skills.

Finally, I think Yager ("Your Questions Answered," 2007) errs in viewing Level 2 or 3 inquiry as needing to represent the transmission model of learning. My experience is that both can offer ample scope for student curiosity and minds-on learning as students design investigative methodologies, analyse data, and/or strive to draw conclusions and justify them. One of my favourite approaches is to begin an investigation at Level 3 (i.e., with students designing a methodology to answer a supplied question), but guiding students in such a way that the deficiencies in their designs become exposed and they end up adopting the procedure that I had in mind from the beginning and for which the required materials are available. In effect, a Level 2 activity is being disguised as a Level 3 one. At the same time, novel approaches suggested by students that are readily implemented can, and indeed should, also be accommodated, and possibly by a subsection of a class only.

Reform visions for science education. I think Robert Yager's reply in "Your Questions Answered" (2007) tends to convey a misinterpretation of Table 2 (p. 109), a table that presents reform visions for teaching. The "more emphasis" column is not intended to represent "recommended teaching features" (p. 107), but rather features that are in need of greater emphasis. Again, balance is the key, with the features in the "less emphasis" column still having a place in sound science teaching. There is still a role, at times, for responding to the group as a whole, demonstration, recitation of acquired knowledge, working alone, and so on. Tables 3 and 4 (pp. 110 & 111), that present reform visions for professional development and assessment, respectively, need to be interpreted similarly.

Distinguishing between the 7E learning cycle and inquiry. The 7E learning cycle, comprising the elements of elicit, engage, explore, explain, elaborate, evaluate, and extend, should not be confused with inquiry. The former involves much more than inquiry, which is basically restricted to the explore and explain elements of the learning cycle only. I disagree with Yager that "such lists . . . do not invite thinking and trial, but rather represent recipes for people to follow with little or no thought. They make it easy for students to follow the science processes with no real effort or personal thinking or reason" ("Your Questions Answered," 2007, p. 105). The 7E learning cycle is a planning tool for teachers, not students, and finding or creating activities to use in the design of learning cycles is a very creative, and demanding, pursuit. And I have already mentioned how engaging students can find Level 2 and 3 inquiry. In fact, just like in science proper, surely a primary goal for science education research is to strive to develop learning theories, which may include models like the learning cycle, to guide sound teaching?

Inquiry at different stages of education. I'd like to share a conclusion I have reached--or, should I say, feel myself reaching--on the basis of particularly my personal experience in having guided, over a considerable number of years, Year 12 high school students as they completed individual, open inquiry, hands-on, experimental projects as a part of their Physics course. In asking myself what they gained from this experience that they would not have been able to gain otherwise during the course, the only thing I have identified is that they had been provided with the opportunity to investigate their own question. However, the price to be paid for providing such an experience for students at this stage of education can be high both in terms of staff time and demands on the budget, as somewhat specialized equipment not commonly found in schools can be required to investigate the questions that interest these students, and I find myself having difficulty justifying this effort being made for such students. Scully (2005) has expressed similar sentiments in an earlier issue of this journal, and notably in the less-demanding context of lower-level inquiry in which all students were using identical materials. The growing trend of experimental work that involves simulations and computer modeling can make life here easier, but I find myself doubting the value of forcing every upper high school student to perform a hands-on, experimental, open inquiry during each of their science courses. Rather, I'm thinking that we might do better to encourage students so inclined to undertake open inquiry as an option by, for example, joining the school Science Club. As Vondracek (2007) notes, "often it is not the straight-A student who does the best research, but the kid who can't stop asking questions or who can't stop tinkering with the demos and equipment we have in our classrooms" (p. 436), and an option like a Science Club would ensure that we don't restrict opportunities for those students so motivated to satisfy their curiosity and to "shine."

However, as Robert Yager advocates ("Your Questions Answered," 2007), the experience of open inquiry certainly does have a place in science education, but I'm inclined to think that this place might be at the primary and middle school levels--the compulsory years of education, if you like--only, where the benefits of engaging in one or more Level 4, open inquiry experiences can be had particularly without the need for somewhat special materials that are not typically available. This thinking appears to be in accord with the situation in universities, where hands-on, experimental, open inquiry in science courses is generally not a priority, with even postgraduate researchers typically operating at Level 2 or 3 inquiry. In other words, how inquiry is implemented might "look different" at different stages of education, and this is not an issue I have seen addressed in the literature to date. Mind you, facilitating open inquiry at any level is a demanding task, especially given the conditions under which many teachers need to operate. I imagine nobody would consider asking an individual university faculty member to supervise up to 150-odd postgraduate research projects, and yet this is effectively what teachers are being asked to do--and within working structures that were designed for a chalk-and-talk model of teaching! The restriction of open inquiry to middle school and below might remove some unnecessary stress on high school teachers? During the past year or so, I have shared this thinking with participants at some of the teacher workshops I have conducted and am yet to find a teacher who has disagreed, and this is giving me increased confidence that the idea may have some validity.

A question. I have a physical science background. When I think of inquiry, I have in mind the picture of students analyzing experimental data that either they have collected or that has been provided for them, and it is from this perspective that I have written the foregoing. However, I'm also now thinking that such a perspective may be limited. In recognizing that an experiment, which involves the control of variables, is only one type of what can be more generally called a scientific investigation (Schwartz, 2007), I'm wondering how my views about inquiry might change as a result of being shown examples of students engaged in investigations in the broader sense. I look forward to what others may have to say on this issue, or anything else I have written.

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Readers' Forum

Inquiry (Continued)

The discussion regarding the meaning and use of the term inquiry is intriguing. I would like to react to and enlarge on some of Peter Eastwell's questions and concerns. Most personal curiosities, if investigated, are guided by past experiences, interpretations, and beliefs of the person who is curious. Hence Peter is correct insisting that there is really no unguided inquiry. To me the important thing is that students be encouraged by teachers and others to pose their own questions--those related to their communities, schools, and families. In Science classes they should be encouraged to identify questions for projects that are: 1) personally relevant and interesting; 2) related to current situations, and 3) locally based. As long as one assumes that such questions can be answered and that possible answers can be evaluated with evidence, it can be argued that this is actually one way of "doing science." Too often dealing with curiosities stop with personal guesses and/or interpretations unrelated to science (i.e., art, literature, and religion).

Eastwell has used the terms "guidance and direction provided," apparently thinking of teachers as providers. It seems to me that this limits the science to curricula and textbook summaries of what we think we know and puts the teacher in the roll of controller of instruction as well as director and initiator of ideas on decisions about what all students should know. These concerns are also noted as Eastwell worries about such questions in terms of fraction of time that should be given to open inquiry in courses. I would be happy if every K-16 Science course required one personal and/or one group project per year where students need to search out information needed to resolve a problem they have identified.

I continue to be concerned that too many students graduate from high school (maybe even college) without ever experiencing one complete experience with science, including using personal curiosities to pose a question about the objects and events encountered, attempting to answer the question(s), collecting evidence for the validity of the explanation(s), and checking with others (experts) concerning the explanations thought to be valid. Perhaps some of the debate about inquiry is caused by lack of agreement concerning what science is and how we choose to define science operationally.

Perhaps an example of open inquiry in Iowa would clarify my position. A chemistry teacher in Western Iowa was asked if he would organize and teach a "special" chemistry course for 15 female students who aspired to be hairdressers. This would be the course to fill his full teaching schedule instead of a teaching section of ninth-grade algebra. After some thought, he jumped at the chance. On the opening of classes in the fall, the teacher asked the students if they could conceive why the school counselor felt that a chemistry course might be useful, indicating that they would not follow a specific curriculum or use a textbook but that he wanted their experience to be meaningful and helpful. He asked the students for ideas of what topics might be studied. After a few days, ozone was mentioned as a problem area. The teacher was surprised to hear the term and the reason it was mentioned, but decided to use the student suggestion, thinking it might take a day or two.

To his surprise, the students never got off ozone that year. He reported that he never expected the student interest and their questions. For example: What does O_3 mean? What is a molecule? What is a solution? What is pH? What are elements? Compounds? The students saw a problem and wanted to help. They became experts! Later, they went to third-grade classrooms to discuss the problem, went to service clubs, and got the town mayor to declare ozone-depletion day in the city! The teacher indicated that the textbooks and other references were found helpful. But much more important was being in touch firsthand with experts.

One interesting comment from the students in several sections of the regular chemistry course was: "Why do those girls get to do all the important and fun things and we are stuck with the next chapter in a textbook and doing cookbook laboratories?" This experience led the teacher to teach the college preparatory courses in different ways.

Another hurried example was a high school where there were a dozen potential school drop-outs. A science teacher was charged with planning a meaningful course designed to keep the students in school rather than on the streets. They were interested in sports--football, expensive tennis shoes--and began discussing relative costs. They got into organic chemistry, polymers, plastics, and differences in sport shoes (the ones “rich kids” could afford). Because of their past poor behavior, they were initially denied use of the school library. The students got more and more involved with questions and activities that interested them. They even became better “school citizens”!

Too often teachers try new open approaches in problem areas, while maintaining the college preparatory functions that chemistry, physics, and advanced biology courses emphasize in high schools. The typical curriculum with discipline focuses characterizes the college science courses completed by most high school teachers. Since most high school teachers have rarely had a firsthand experience with science inquiry, many hesitate to change their teaching approaches.

It is planned that the November, 2008 issue of the NSTA *The Science Teacher* will emphasize examples of teaching science via projects designed for solving problems. NSTA is also publishing a sixth monograph as part of its Exemplary Science Program (ESP) dealing with inquiry. All chapters report on using situations that are offered as samples of an inquiry focus in K-12 classrooms, informal education arenas, and teacher preparation and professional development programs.

Eastwell asks for evidence that open inquiry is desirable and then calls unguided (open) inquiry “poor pedagogy.” If it is, why is there so much research indicating the advantages of it? When courses or units are approached as open inquiry, the following things happen:

- More positive attitudes develop for more students concerning science study, science careers, and science teachers;
- Students become more creative persons in terms of defining and refining their own questions and proposing possible answers;
- Students with open inquiry experiences are able to use the skills and concepts that characterize science courses in new contexts;
- Students who perform as open inquirers usually want more of it.

These all happen in varying degrees depending upon whether it is a 5-day trial, a 3-week unit, or a departure from the course guide for a semester or a whole year.

Researchers stress that the open inquiry approach is especially powerful in engaging low-ability and problem students in the learning process. Many assume that more learning results when it seems like play or comes from free choices. Often teachers get more comfortable not being the “sage on the stage” and see the advantages of student input, ideas, and problem identification/resolutions for mind engagement and success.

When used with high-ability students, some research illustrates that later instruction in college courses is criticized. In other words, there are now many college science faculty members willing to try problem resolutions and more student-centered approaches even in large lectures. Many institutions with model teacher education programs are assisting college teachers to do something more than sharing what they know with students, thinking the best students seem to learn what they are told or what cookbook labs illustrate.

Sometimes high-ability students who experience science as traditionally offered in high schools are negative with respect to inquiry foci because of their great success with being told what to do and following directions correctly. They do not like changes from the traditional teacher-directed classrooms in which they excelled; never questioning that their real learning was in question and perhaps alien to science itself. It seems to me that good teachers should always be a bit dubious about real learning and expect students to show their "knowing" by use of the information and/or skills in new situations.

Peter Eastwell has spent much time defining scientific inquiry, inquiry activities, and inquiry levels. Certainly these ideas and terms are useful as we all seek for more success with student learning in Science. It is important that we agree on definitions and that we see a use for them in our teaching and our efforts to improve. As indicated earlier, I prefer a more generic use of the term--not putting science and scientists on pedestals.

I like Eastwell's idea that open inquiry may be more important for elementary and/or middle schools. I agree; but my position is that most elementary and middle school teachers are very willing to admit that they do not know basic science. It is easier to convince them to try and to work with students without the problem of knowing too much--too much for students to learn--and deal with things they do not know with their own students. Perhaps the best model for an inquiry teacher is not sharing the things he/she knows but helping students advance their own unknowns by searching out ideas from others; students, parents, community leaders, professional scientists, and engineers. It may even be useful if the searches result in opposing views/ideas. The inherent student interest makes all of this easier to accomplish.

Modern science demands collaboration, where many views and ideas are shared. Why not so in science classes? It may be desirable if there are multiple differences in problem identification and proposals for their resolution. Too often students are denied experiences with the essential features of inquiry. In a sense, we are all guided by experts we seek out, written materials, and other people (including students) with whom we are in contact. Too often we as teachers feel content that we know what students need and will be able to use. Few doubt their wisdom. One Iowa biology teacher took great pride in former students returning to her classroom with praise, indicating that they were still using her notes taken in 10th-grade instead of those from the college instructor in whose course they were now enrolled. This judgment and compliment caused the teacher to continue giving students fine lectures, chalkboard notes, and promises that all the information was important and would be useful.

How could real inquiry by individual and/or groups of students be poor pedagogy??

Robert E. Yager, University of Iowa, IA, USA

While reading Robert Yager's foregoing contribution, my initial reaction was to ask why what I had been trying to communicate was being so misrepresented. After subsequent pondering, communications with Robert, and further reading, I have concluded that the reason for this, and for why Yager and I appear to be "talking past one another" rather than with one another, is that we still have differing views of what it means for students to be engaged in inquiry. So, given that what I have written previously appears to have been insufficient, I now welcome the opportunity to elaborate and, hopefully, clarify.

Definition of inquiry. I have previously distinguished between scientific and non-scientific inquiry (i.e., types of inquiry), and also between scientific inquiry and inquiry Science (the learning/teaching model). Further, in the context of the latter, I have used the definition of an inquiry activity as being one that requires students to answer a question by analysing information themselves. However, I now see the need to be more specific and note, in particular, that the information referred to here needs to be raw, empirical data. In short, then, an inquiry activity is one that requires students to answer a scientific question by analysing raw, empirical data themselves.

Let us consider the implications of this concept, as reflected in the work of others such as Dobson (2008), Farrell, Moog, and Spencer (1999), Leege (2008), Lunsford and Slattery (2006), and Wilhelm, Smith, Walters, Sherrod, & Mulholland (2008), for classroom practice. I have also mentioned previously that the data students analyse in an inquiry activity may be supplied by the teacher, collected by students, or a combination of these. As a good example of the former, consider how time-consuming, costly, and finicky it can be to have groups of students set up and use Millikan's apparatus to determine the fundamental charge, *e*. In any case, the focus in this exercise is on the data analysis rather than on gaining anything special from the process of setting up the apparatus. So, in accord with the suggestion of Pearson (2005), it might be preferable to provide students with some of Millikan's original raw data (e.g., different groups could be assigned data for different size drops), a description of the apparatus (a video or computer simulation showing it in action would be even better), and the relevant equations and invite them to use Microsoft Excel to analyse the data to determine the fundamental charge, *e*.

However, it is far more common for an inquiry activity to require students to collect data themselves (just like scientists need to do), and an excellent example of such an activity is an investigation students might perform to answer the question: "Does eating spicy food cause your core body temperature to rise?" During such an activity, the work of students also reflects the core work of scientists. The research, or investigatory, approaches of scientists may be categorized as experimental (traditional manipulative investigations comprising the control of variables and the assessment of cause and effect relationships), descriptive (correlational and/or observational studies, void of direct manipulative features and including modeling systems that use computer simulations developed from collected data), experimental/descriptive combination, or theoretical (comprising mathematical computations) (Schwartz & Lederman, 2008). While the latter is not really applicable to the school context, the scientific inquiry of scientists focuses largely on understanding the causal mechanisms that underlie natural phenomena (Russ, Scherr, Hammer, & Mikeska, 2008).

Now, here comes a key point that I think will illuminate a major difference I seem to have with Yager about the concept of an inquiry activity in science education. Consider the following questions: "How does electricity pass through a wire?" and "Did the cavemen have cats? Can you think of an investigation that students might perform to answer either question? No. These questions are not investigable in the school context. However, they might be readily answered by performing a library/literature search. Here, though, the information that students will be retrieving is not raw, empirical data for analysis (as is required in an investigation) but rather the conclusions of others (based on analyses that have already been completed) and, as Bell, Smetana, & Binns (2005) make clear, the retrieval of such information does not constitute inquiry. This is also in accord with the work of scientists, who do not typically investigate by simply synthesizing the conclusions of others. For this reason, then, I suspect that the ozone and sport projects Yager mentions also do not constitute inquiry.

At the same time, though, what are often called library research projects, that require students to find and process information other than raw, empirical data, can certainly make a valuable contribution to a curriculum, even though they do not constitute inquiry. In fact, a question might not even be involved. For example, Tribe and Cooper (2008) report on how a literature research project, which involved students collaborating in groups as they researched topics including The Effect Acid Rain has on Urban Environments and The Fermentation of Beer to produce a poster session, was successfully used to introduce students to peer-reviewed literature. Such projects, which include WebQuests, can also be useful for learning about socioscientific issues/problems, and controversial issues in particular, as in the case of trying to answer the question: “What is the best solution to a Foot and Mouth disease outbreak in this country? However, the treatment of socioscientific issues also requires a consideration of factors that are outside the realm of the nature of science; social, political, or economic concerns, value judgments based on beliefs, cultural differences, moral considerations, etc., personal opinion, and the like. By incorporating non-scientific considerations (e.g., personal opinions that are not based on empirical evidence and that cannot be tested), such activities cannot constitute inquiry (although the scientific components of them certainly could) and other strategies are available for dealing with such issues in the science classroom (e.g., see Oulton, Dillon, & Grace, 2004). Consider, then, the work reported by Yager, Kaya, & Dogan (2007) in which groups of students identified and aimed to resolve science and technology problems that included AIDS and Chemical War Gases and Their Characteristics using library and on-line searching, campus-based symposia, and communication with experts and then presented poster sessions. While the article does use the terms *inquiry* and *data*, I’m inclined to think that *project* and *information* (to describe the photographs, interviews, and “hundreds of pages of information”), respectively, might be more appropriate.

I should emphasise, though, that library searches are certainly not incompatible with inquiry learning. Consider, for example, the question: “What local climate changes, if any, are associated with El Niño?” A non-inquiry way to answer this question would be for students to retrieve the required information from the library and summarise it. However, an inquiry approach might see students using a library/on-line search to find the monthly temperature (and rainfall, etc.) data for their location for the most recent El Niño year and comparing it with the monthly averages for the past 50 years (Bell et al., 2005). Also, just as scientists use the results of literature reviews, information that is not raw, empirical data that comes from sources like library reviews can contribute to the report of an inquiry activity by providing background to the activity and/or being linked to the results of the inquiry in the conclusion section of the report.

So, this will hopefully make clearer why I am suggesting that Yager’s more general (“generic,” as he has called it) use of the term inquiry to mean "questioning in order to get information" is insufficient. In summary, inquiry (in the context of the inquiry Science model for teaching/learning) must see students answering scientific questions (not socioscientific questions, and obviously also not non-scientific questions) by analysing raw, empirical data (in contrast to evaluating and synthesizing the conclusions of others). To me, attempting to apply what the National Science Education Standards (National Academy of Sciences, 1995) has to say about inquiry to these other contexts does not make sense. As an aside, and a note of caution, though, we do appear to have some way to go in our understanding of how such projects, in the broader context, might be best implemented because, as Tai, Sadler, and Loehr (2006) found, “students who reported being assigned greater numbers of independent projects [in high school chemistry] typically earned lower grades in college chemistry” (p. 125). This clarification will hopefully also assist communication between science educators, because it is difficult for people to discuss an issue by using a term like inquiry without sharing the same definition of the term.

Allow me to conclude the treatment of this issue by sharing an example of how the lack of use of a common definition of inquiry might lead to much confusion. Imagine a science education research manuscript titled “An Inquiry into Teachers’ Inquiry of Inquiry Learning.” Confused? Well, if you’re not confused by the use of the term inquiry in the title, you probably would be confused by its use as you read the manuscript proper. Here we have the situation of teachers who have investigated aspects of inquiry learning in the classroom and an academic who has studied the processes undertaken by those teachers. Now, assuming that the work of both the academic and the teachers included obtaining data in the affective domain, for example, none of them have done either science (because the personal opinions of people do not constitute scientific data) or inquiry in the spirit of the Inquiry Science model for teaching/learning. Rather, they have conducted social science research, and a preferable title might be “A Study of Teachers’ Investigations Into Aspects of Inquiry Learning,” even though the term *investigations* is not being used in the scientific sense.

How much inquiry? The motivation for me asking what fraction of a course might best be Level 4 (open) inquiry (i.e., students designing methodologies to answer their own questions) was two-fold. First, I was asking Robert Yager to be more specific as to how much open inquiry he was recommending, because his descriptions of “open inquiry is what we should be aiming at” and “one activity per term, or whatever, as a start” (R. Yager, personal communication, May, 2008) were not sharing a clear vision. In particular, I was very keen to be critical if it turned out that he was advocating that an entire typical science course might be based on students’ questions. I’m content with his suggestion of one or two open inquiries per year.

This is also in accord with what others have been saying about inquiry in general (i.e., not Level 4 inquiry in particular). For example, “inquiry-based practices should be used as often as is practical. If students perform even a few inquiry-based labs each year throughout their middle school and high school careers, by graduation they will be more self-confident, critical-thinking people who are unafraid of ‘doing science’” (Deters, 2005, p. 1180). The phrase “as often as is practical” is important. For example, unlike in general chemistry, Level 3 inquiry (i.e., students designing their own procedures, whether in part or completely) is problematic in organic chemistry (Horowitz, 2007; Mohrig, 2004). Here, lower-level “cookbook” activities appear to have a valuable role (Ault, 2002), provided the recipes are not so dumbed-down as to require no thinking on the part of students (e.g., some information is left for them to figure out for themselves) (Horowitz, 2008).

In the event that there are readers keen on the idea of basing typical science courses on students’ questions completely, and even perhaps on project work aimed at answering these questions, allow me to share the following thoughts:

- There is no guarantee that students themselves will identify all the key concepts in a field of study that a graduate of a particular course might reasonably expect to have been exposed to.
- "It is clear that the biology curriculum cannot rely solely on students' interests" (p. 537) because, for example, they rarely asked questions about current topics such as biotechnology” (Baram-Tsabari & Yarden, 2007).
- Baram-Tsabari and Yarden (2007) wonder if free-choice learning might lose its appeal once it became compulsory, at the same time acknowledging that taking students’ interests into account is important. Again, as is typical in the field of education, an appropriate balance appears to be the key.
- “We suggest that a ‘some research curriculum’ [this includes projects] is good, but that an “all research curriculum” is both unnecessary and inefficient” (Brooks, Schraw, & Crippen, 2005, p. 643).

My second motivation for asking what fraction of a course might best be Level 4 (open) inquiry was linked with the idea that the amount of open inquiry might vary with year level in school, and to particularly test my suggestion that Level 4 inquiry (involving students using hands-on activities to collect data to answer their own questions) might not be a priority after, say, the compulsory years of education because the outcomes might not warrant the price to be paid in terms of the demands on budgets for somewhat specialised equipment and staff time. My suggestion would be weakened if there were examples of Level 4 inquiry being used in science courses throughout the tertiary (university) sector, so I have been most vigilant in trying to identify such in my reading. However, I am yet to find a single one, with the closest I have been able to find involving Level 3 inquiry only (Apedoe, Walker, & Reeves, 2006; Lord, Shelly, & Zimmerman, 2007). In fact, in the paper of Apedoe et al., whose work in implementing inquiry in geological science I regard to be exemplary, we find open inquiry mentioned early as a desirable aim but a later admission that the best they could do is Level 3 inquiry, with students also needing to be provided with a multitude of data from which to formulate their explanations. As Brooks et al. (2005) say, and in accord with the reasoning of Cheung (2008), inquiry is a difficult business and, to make inquiry work in real teaching situations, a lower-level inquiry strategy is employed.

The issue of guidance. Robert Yager writes: “How could real inquiry by individual and/or groups of students be ‘poor pedagogy’??” While *real* is not defined, I think we can assume from what he has written previously that he means open, unguided inquiry and that he is confusing open (Level 4) inquiry with unguided inquiry by incorrectly equating them. Now, I haven’t called open inquiry poor pedagogy. Quite to the contrary, I am aware of the evidence supporting inquiry learning and am a passionate supporter and user of the approach, but am simply questioning the use of one level of it only in one particular context; namely, open inquiry in upper secondary Science courses. What I have done is distinguished between the degree of direction and the degree of guidance provided to students and provided evidence for why unguided learning is poor pedagogy. In addition, I am not viewing guidance in the indirect, passive manner that Yager describes but rather in a direct, active way. I would welcome being shown evidence for unguided learning being superior to guided learning, but nobody has yet supplied such and I haven’t been able to find any. Indeed, quite the opposite is the case, with support for guidance common in the literature. Let’s consider some of this support.

Yager writes: “As long as one assumes that such questions [the questions students have posed] can be answered.” Well, the evidence is that we can’t make this assumption, and that students need guidance to ensure this point in a Level 4 (open) inquiry is reached. Chin and Kayalvizhi (2002) found that, in the absence of guidance, only 11.7% of the questions posed individually by Year 6 students for hands-on investigations were investigable. They concluded that pupils’ “raw” questions do not seem to immediately lend themselves to practical investigations but that peer and teacher guidance can help to rectify this situation.

Further evidence for the value of guidance comes from the following:

- “Successful instruction nearly always includes performance-related feedback” (Brooks et al., 2005, p. 643).
- “My job is to guide students in their question asking, experimental design, and interpretation of results” (Dobson, 2008, p. 43).
- “Journals also give teachers a way to provide feedback to students to help guide their work” (Peters, 2008, p. 27).

- "The level of Instructor Support was the strongest independent predictor of student attitudes" (Martin-Dunlop & Fraser, 2008, p. 163).
- "Teachers play a critical role in open inquiry learning. Their role incorporates guiding, focusing, challenging, and encouraging students to engage in this type of learning" (Zion & Shedletzky, 2006, p. 23).
- "Students who receive frequent feedback about their ideas during the inquiry process tend to develop more complete understandings of science" (Donovan & Bransford, in Peters, 2008, p. 31).
- "Teaching an interactive inquiry course requires teachers who believe that students are capable of independent learning given proper guidance and support" (Lord et al., 2007, p.65).
- "What these classroom-based studies tell us is that learning to generate and use scientific explanations is a reasonable expectation in elementary science classrooms, but it does not happen automatically without specific scaffolds provided by the teacher (Gagnon & Bell, 2008, p. 61).
- In relation to the use of asynchronous, on-line forums to help students with open inquiry: "The results . . . indicate that students required assistance mainly with searching scientific information, finding experimental techniques and procedures, and phrasing inquiry questions" (Zion, 2008).
- "Most of the teachers initially described inquiry as a 'student centered method of teaching' (Lisa) where 'students create their own knowledge and are responsible for their own learning' (Roberta). . . . By the close of the semester, the idea of the teacher as a guide, or facilitator, was incorporated into their definitions" (Moseley & Ramsey, 2008, p. 53).
- "The importance of having an instructor who is comfortable and skilled in facilitating and guiding inquiry is clear. Without appropriate instructor guidance and facilitation, students may become frustrated because they are unable to reach understanding of the scientific concepts on their own" (Apedoe et al., 2006, p. 420). "Instructors must learn to walk a fine line between providing too much support and thus maintaining the teacher-centered nature of traditional science courses at the undergraduate level, and too little support that would leave students floundering without sufficient scaffolding" (p. 421).

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