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Leadership in Science Education: Focusing on the Unknown and Moving to Knowing

An argument is made that science leaders must take the goals of science education seriously and use them to frame our teaching and staff development efforts.

Never has there been a time when the need for creative leadership is more needed in schools to ensure that the focus is upon meeting the major goals on which there is agreement. Effective leaders should not portray themselves as knowing what an exemplary science education is and then forcing all persons in the district to move toward it. Instead, as in science, it is first important to know what the issues, questions, and problems are and then move toward answers and solutions—perhaps slowly and taking time to amass evidence that the various actions undertaken indeed are appropriate ones for meeting the agreed upon goals.

The National Science Education Standards (NSES) clearly articulates four goals (justifications) for requiring science in K-12 schools. These four goals are producing students who can:

1. experience the richness and excitement of knowing about and understanding the natural world;
2. use appropriate scientific processes and principles 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 and understanding, and skills of the scientifically literate person in their careers. (NRC, 1996, p.13)

For many the first goal is the most important since it ensures that every student will have a firsthand personal experience with science. This means exploring nature with a natural curiosity, which all humans enjoy. It means asking questions, identifying the unknown, proceeding to knowing—even if it is a personally constructed answer or explanation (but wrong in terms of current science academy notions) of the original question arising from personal curiosity.

Most laboratories are but verification activities of what teachers and/or textbooks have indicated as truths about the natural world.

Enlarging Our Visions of Science

Science educators tend to define science as the information found in textbooks for K-12 and college courses or the content outlined in state frameworks and standards. Such definitions omit most of what George Gaylord Simpson (1963) described as the essence of science; Simpson's five *activities* which define science are:

1. asking questions about the natural universe; i.e., being curious about the objects and events in nature;
2. trying to answer one's own questions; i.e., proposing possible explanations;
3. designing experiments to determine the validity of the explanation offered;
4. collecting evidence from observations of nature,

mathematics calculations, and, whenever possible, experiments carried out to establish the validity of the original explanations; and

5. communicating the evidence to others who must agree with the interpretation of the evidence in order for the explanation to become accepted by the broader community (of scientists). (Simpson, 1963, p. 3)

Science education should be about drawing people out in terms of engaging their minds.

The elements of science identified by Simpson are rarely studied in schools. For example, science students seldom determine their own questions for study; they are not expected to be curious; they rarely are asked to propose possible answers; they seldom are asked to design experiments, and they rarely share their results with others as evidence for the validity of their own explanations (Weiss et al., 2001).

One could argue that "real" science is seldom encountered or experienced in most science classrooms. The typical focus is almost wholly on what current scientists accept as explanations (Harms & Yager, 1981; Weiss et al., 2001). Competent science students only need to remember what teachers or textbooks say. Most laboratories are but verification activities of what teachers and/or textbooks have indicated as truths about the natural world. There is seldom time for students to design experiments that could improve human existence.

Science education should be about drawing people out in terms of engaging their minds. Instead, most science programs focus on directing students to what they should learn—i.e., the explanations of objects and events that scientists have accepted as truths or explanations of the natural world and/or technological achievements (e.g., automobiles, airplanes, air conditioners) (AAAS, 1990). Education has become *training*; i.e., getting students to accept and be able to recall explanations others have offered. This is often done under the guise that specific concepts and process skills are necessary prerequisites for understanding even though it is now apparent that such approaches are useless and that understanding is rarely accomplished until students see the importance and the need for them (Resnick, 1986; NRC, 1996; Greeno, 1992).

NSES and Changing Goals for Science Education

The first and overarching goal for science education for the decade following the 1996 publication of the NSES provides a direction for our field—every school science coordinator, supervisor, curriculum leader, and department head must internalize and work diligently toward meeting it. It should be the goal that unifies us all. But, it will be the most difficult to achieve. School science is rarely seen as an experience that enriches and excites students about their knowing and understanding of the objects and events found in the natural world.

Paul Brandwein once said that science literacy would begin to be realized if every student had one experience with science as it is defined by Simpson (1963). Brandwein contended that most high school graduates complete their schooling without even one experience with real science. Many within the National Science Teachers Association (NSTA) have argued that we should aim for more than one science experience in thirteen years—instead at least one each year of the thirteen year continuum of a general education for all. Most teachers would argue that thirteen such experiences are but "a drop in the bucket."

Many high school teachers enjoy teaching the best students who are preparing for college and not for meeting any other goal or benefit for their study.

The other three goals from the NSES focus upon experiences in school science which will affect the daily lives of students that can help them make better scientific and societal decisions and lead them to increased economic productivity. These are almost identical to three of the four goal clusters Norris Harms used for his NSF-supported effort conceived in 1977 called Project Synthesis (Harms & Yager, 1981). The four goals Harms used were:

1. Science for meeting personal needs. Science education should prepare individuals to use science for improving their own lives and for coping with

an increasingly technological world.

2. Science for resolving current societal issues. Science education should produce informed citizens prepared to deal responsibly with science-related societal issues.
3. Science for assisting with career choices. Science education should give all students an awareness of the nature and scope of a wide variety of science and technology-related careers open to students of varying aptitudes and interests.
4. Science for preparing for further study. Science education should allow students who are likely to pursue science academically as well as professionally to acquire the academic knowledge appropriate for their needs. (Harms & Yager, 1981, p7).

Project Synthesis was funded and carried out at a time of great disillusionment in the U.S. about the purposes and directions that science education had taken in the years after the Soviet Sputnik caused Americans to question what they were doing in school science. The period ushered in reforms—the likes of which were contrary to nearly forty earlier national reform efforts for school science. Until the 1959-70 reforms funded by NSF, national reforms had all focused on a science that was tied to daily living—a science that had practical utility and included (perhaps used) technology. The post-Sputnik era focused on producing and advocating science as it is known to scientists (in terms of processes/skills used in laboratories and the most recent explanations arising from their research).

Project Synthesis revealed that goal four (preparing students for further study) was the only one for which teachers justified what they were doing. In excess of 90% of all U.S. science teachers justified their teaching and curriculum because the next grade level "expected" it. The information and skills were thought to be important and useful to the next teacher. The greatest justification was in the high schools where the discipline bound (sometimes called the "layer cake") curriculum was firmly entrenched. This was caused by Harvard University requiring high school physics for entrance in 1892; ten years later they required chemistry. Many of the universities followed the Harvard lead with most high school science offerings seen primarily as prerequisites for college entrance. We know today that chemistry and physics were offered primarily for college preparation with advanced biology often included for the same reasons in grades 11 and 12. Many high school teachers enjoy teaching the best students who are preparing for college and not for meeting any other goal or benefit for their study. And yet, there is little evidence that any teacher (at the next teaching level) actually builds on what is taught earlier.

While most teachers accept the importance of student-centered approaches, few students ever sense that typical classrooms result in their being partners in learning rather than recipients of it.

It is refreshing to note that the academic preparation goal that framed Project Synthesis is not included as one of the NSES goals even though it was the one on which nearly all concentrated and used as justification for their teaching practices. It is also noteworthy that the other three goals—not approached well nor achieved in 1980—remain major goals for the current decade.

Instruction and Curriculum and Meeting the Goals

But, what is done in typical schools that is designed to specifically meet (or move toward) any one of the four NSES goals? The curriculum has remained rather static. In spite of the NSTA Scope, Sequence and Coordination Project (NSTA, 1992) (designed to eliminate the "layer cake" curriculum), the same curriculum seems to exist and flourish. Textbooks rarely focus upon anything but the same content strands, which characterize most state standards, the same topics in standardized assessment schemes, and the content frameworks characterizing textbook adoption states.

If we are to meet the four NSES goals, much more attention to them is needed. More discussions of how each could be met, how teaching must change, how the curriculum materials must change, and how evidence can be amassed to determine the degree the goals have been met.

Science leaders must help practitioners to change their instructional strategies. Again the NSES clearly state nine ways teaching should change to result in more and better student learning and to move toward meeting the stated goals. These changes are summarized in the NSES

Table 1

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

(NRC, 1996, p 52)

as contrasts between "less emphasis" conditions (which are commonly used strategies by most teachers) to the "more emphasis" conditions (see Table 1).

Interestingly the teaching standards are first in the 1996 publication because of their importance in realizing the goals and because they were the least controversial of all the visions contained in the NSES. Science education leaders and programs they organize for teachers should concentrate their attention on ways to meet the four goals—rather than on adaptation and implementation of curricular materials (which most consider first as reforms and changes are contemplated). Most of the new materials (even those supported by NSF funding) contain few instances or pathways for meeting the four stated goals from the NSES.

It could be a worthwhile exercise to examine state standards, most popular texts, and teacher lesson plans in a search for any evidence that instructional strategies, content, and lesson plans reveal any indications that they will help students ask a question about the natural world and offer possible explanations, devise tests to determine the validity of the explanations, enter into dialogues with others concerning the explanations (attempts to meet Goal One of NSES). And, are there any indications the changes encouraged or impacted the way students live their daily lives (attempts to meet Goal Two)? Is there any evidence that instruction or curriculum provides experience or information about solving societal problems? Are there any attempts to tie science learning to economic productivity and possible careers?

Questions provide the heart of science.

The Centrality of Questions

Central to science are questions! Science begins with the unknown and it is the goal of science practitioners to move to the known.

Perhaps in science education we need more science concerning our own profession—that is questioning how we teach, what we teach, whether our teaching results in more and better learning, and whether our efforts are helping us meet our stated goals.

Science begins with questions and as they are considered often more questions emerge. Some would argue that all real learning starts with a question and not a teacher assignment or a textbook suggestion. The NSES visions for teaching invite student involvement.

While most teachers accept the importance of student-centered approaches, few students ever sense that typical classrooms result in their being partners in learning rather than recipients of it.

Students must be involved with problem identification and question-asking. Science lessons need to include open entry in addition to student ideas about possible answers, student designs of experiments, open-ended laboratories. And yet far too little is known about "problem finding." Penick (1996) used Dillon's work (1982) in this regard as he urged teachers to focus on stimulating more creative students. Dillon pointed out that "few abilities or accomplishments have been praised or rewarded less than problem finding. Yet, compared to the volume of literature on problem solving, there is almost nothing written about the process or learning of problem identification. As a result, no theory of problem identification has been put forth." Dillon also noted that problem finding, including discovering, formulating, and posing questions, may represent a more distinct and creative act than finding a solution. Many writers (Getzels and Csikszentmihalyi, 1975; Mackworth, 1965) have concluded that question posing and problem finding are crucial, at the heart of originality, and form an extremely strong association with creativity. Yet, in most educational endeavors, problem finding is ignored while concentrating on the more mundane aspects of solving problems presented by the text, the teacher, or worksheets. Paul Hurd (1991) has suggested that we should leave problem-solving to the mathematicians. Few science problems can be solved in a class period, during a grade period, or often in many years.

Einstein has often been quoted as saying that "raising new questions new possibilities, regarding old questions from a new angle all require imagination and creativity". Questions provide the heart of science. We all need to help students to question more, to act on their natural curiosities, to experience the excitement and thrill of the whole scientific process (Goal One of the NSES).

Table 2. Percentage of Students Demonstrating Creative Thinking in STS and Textbook Courses

	STS Classes	Textbook-Driven Classes
Questions	81	30
Unique Questions	70	13
Explanations	87	11
Unique Explanations	68	6
Tests for Validity of Explanations	71	14
Unique Explanations	51	5
Distinguish Between Cause and Effect	91	43

Creativity and Communication in Science

Students with creativity, curiosity, and questions often desire to communicate (Risi, 1982). When one discovers, does, or invents something, a natural first response is to let others in on the excitement. Without communication of ideas, science would not exist as we know it. It is one of the essential features of Simpson's definition cited earlier. Chaudhari noted that "Students' questions are their curiosity in action, their mind hunger" (Chaudhari, 1986, p. 34-36). But, Penick (1996) argued that if students are to communicate effectively and to formulate and follow-up on questions, they must have a classroom climate where creativity is valued, encouraged, modeled, and rewarded. This environment is well exemplified by the Science-Technology-Society classroom. A variety of studies have examined creativity as a result of STS instruction. Myers (1998), Foster and Penick (1985) and McComas (1989) used the Torrance Tests of Creative Thinking. In all cases the investigators found that students scored significantly higher after experiencing STS classes than after learning in a more traditional classroom. Table 2 indicates typical results attained in studies resulting from the Iowa Chautauqua Program, which has sought to encourage the NSES visions with an STS approach.

Mackinnu (1991) also reported on a study using fifteen creativity measures. He found that STS students showed significantly more gain on every item than students from more text-oriented classrooms. These results are what one would expect considering the fact that classrooms employing the STS approach encourage student ideas, initiative, and communication with other students. These results are also significant in the sense that we all want students who can raise questions, suggest causes, and predict consequences. Yet, while all teachers involved with implementing NSES goals are overtly seeking these outcomes, more typical teachers only hope for them as a by-product of didactic instruction.

In addition to all these studies having similar findings, there is a common thread that ran through all the classes taught by teachers enthused with the NSES and the four stated goals. The common thread was a stimulating classroom climate where student questions and ideas were valued, their initiative encouraged, and where evaluation was based on a wide variety of criteria. This classroom climate, an essential element for both creativity and teaching advocated in the NSES, is made possible only by the teacher.

Science education leaders must portray science and constructivist practices if the reforms envisioned by NSES are to flourish.

Penick (1996) has suggested that the teacher must be involved in this initial part of "sciencing". Teachers must provide students with considerable intellectual freedom, safe opportunity, and time to be spontaneous, explore, test, decide courses of action, and take risks. Students will not ask questions if they feel they and their questions may be pushed aside, rushed, or subject to ridicule. A rush to judgment is the opposite of creativity.

The teacher is uniquely important in enhancing such creativity. Well-posed questions stimulate thinking, revealing alternate points of view and logic, and may be viewed as the embodiment of curiosity. But, to be a model of creative inquiry, a teacher must use questions that go beyond mere description. Questions to stimulate creativity must require and allow multiple possible answers and demand actions. Questions model thinking as relevant problems are pursued. Questions act as windows on the phenomenon in question and continue the process until the desired evidence or explanation have been revealed.

Crafting Appropriate Questions

Penick has noted that the tendency is often for teachers to ask the ultimate question, "Why?" When a phenomenon is introduced and teachers ask, "Why did that happen?" students are put off because the "why" sounds very absolute and threatening. "Why" implies someone knows (or should know) the answer or is possibly wrong (Why did you hit your little sister?" A better approach is to begin with the concrete, asking questions about what students did or what was observed. Then, ask how they might do it differently and what might happen if…? Predictions are a reasonable next step as well as questions seeking to determine relationships with other, similar phenomena. Since we consciously model good question-asking behaviors, then types of questions follow a logical hierarchy that students can emulate. We want them to delve into the problems and these assist in that endeavor. The "why" questions sound like test questions and are best if never asked. Table 3 suggests a simple hierarchy of questions which may

Table 3. Penick's Hierarchy for Questions in Science Classrooms

1. Asking questions that describe:
    a. What you did?
    b. What happened?
    c. What did you observe?
2.Asking questions that predict:
    a. What you will do next?
    b. What will happen if you…?
    c. What could you do to prevent that?

3. Asking questions that relate to situations with others:
    a. How does that compare to…?
    b. What did other people find?
4. Seeking explanations:
    a. How would you explain that?
    b. What caused it to happen?
5. Asking for advice:
    a. What evidence do you have for that?
    b. What leads you to believe that?

Penick, 1996, p. 89

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be asked to help organize the questions teachers interested in creativity enhancement should ask.

Table 3 is an elaboration of Penick's suggestions for a hierarchy for questions. This is an important contribution for science educators who wish to help teachers in analyzing and using their own questions and those of their students. It is a way of helping teachers and their students in recognizing and using questioning as a central ingredient in science and where the thinking, reflection, and learning of science should begin.

Table 4 is Penick's attempt to outline ways teachers and professional developers can increase student involvement and creativity in science classrooms. He has recommended that we ask questions to obtain information, not to test students. When we seek information, we do not ask questions if we already know the answer. In good adult conversation, adults ask each other questions to find out, not to examine. We would not spend much time with an adult who continually quizzed us, particularly if they followed up by evaluating our answers. Our students are not different except they are captives of our classroom. As a rule of thumb in the classroom, if you wish to stimulate student involvement and creativity, never ask if you already know. We should also seek opinions and points of view such as, "How would *you* design an experiment to …?"

To stimulate multiple answers, we must accept all answers, regardless of how good they may be. To encourage students to tell us their thinking, we must show them that each of their ideas has value, that we are paying attention to them. And, since evaluation stifles creative thought and reduces thinking initiation, we must avoid judgment. But this does mean we let everything pass by without comment or is it a matter of evaluation avoided? In fact, evaluation and assessment are vital parts of science. They are seen as critical parts of what science is about. (One might consider again Simpson's definition of science.) Science education leaders should focus on questions, possible explanations, and the design of tests for the validity of personally posed tests in professional development efforts for teachers. It is too common to find new programs (e.g. kit-based programs) with no rationale, and no reference to NSES goals.

A Charge for Teachers

Science education leaders must portray science and constructivist practices if the reforms envisioned by NSES are to flourish. Already eight years have passed since the first versions of the NSES were available. Unfortunately too little has occurred to change teachers and their classrooms to generally accomplish the reforms needed. It will take concentrated and prolonged efforts to succeed.

Science coordinators, curriculum experts, department heads, and others in school districts must take the lead. Such leadership should take the goals of science education seriously and frame all we do. At this same time we need to identify ways of knowing if our goals have been met prior to our teaching and any staff development

Table 4. Penick's Suggestions for Making Creativity Flourish in Science Classrooms

1. Provide opportunities for creative work:
   (Time, material, expectations)
2. Ask questions that demand answers:
   (no "yes/no, recall, or answers you already know)
3. Wait for responses;
   (Don't rush, if you really ask a question, wait for the answer. And wait again for multiple responses)
4. Accept unusual ideas, questions, or products:
   (No judgment, just acknowledge and ask for more)
5. Ask students to examine causes and consequences:
   (If that's true, then…?, What may have caused that?)
6. Allow students to make decisions:
   (Structure activities so that decisions must be made and allow students to do so)
7. Model creative thinking, action, and decision-making:
   (Ask questions yourself, express curiosity, make the classroom stimulating)

Penick, 1996, p. 90

efforts. If we want students to experience the thrill and satisfaction of raising questions about the natural world, we must encourage it at all levels and at all times. If we expect science to affect our daily lives, help with decision making concerning science issues, improve economic productivity and choice of careers, we need to help practitioners with their teaching strategies, curriculum materials, and assessment techniques which illustrate the NSES visions.

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