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How are we Stacking Up?: Current Reforms in Science Education Twelve Years after Publication of the National Science Education Standards

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ABSTRACT: In education Science-Technology-Society (STS) is commonly viewed as another add-on to a course or the curriculum. This view portrays STS as being plagued with the same problems as traditional teaching of science and technology; information is transmitted to students by lecture, verification laboratories, or textbooks and other written materials. This article presents the case that STS instruction, when effectively implemented, captures more broadly key aspects of both science and technology, and does not succumb to the common problems of traditional instruction. Essential characteristics of effective science teaching are presented.

STS and Science Education Reform Efforts

Science education has been in the public eye and perceived to be in turmoil since 1957 with the Soviet exploits in outer space. Interestingly, technological success brought significant funding for science education in response to the perceived supremacy of the Soviets. Soviet success was thought to be linked to the quality of their K-12 and undergraduate college science compared to the situation in the U.S. This was the period prior to STS emerging as a reform effort in Europe during the 1970's, and a decade later in the United States.

Although STS became a popular reform effort during the 1980's, it also became very controversial with many scientists and educators both declaring that STS was really an acronym for Stop-Teaching-Science. However, many STS enthusiasts were not offended because STS demands that science (and technology!) be taught in a vastly different manner. STS advocates merely added: Let's Stop-Teaching-Science in the same old “failing” ways! Many new moves for reform reflected the cognitive science research of the last several decades, where the focus is on learning rather than merely teaching a set curriculum.

Too few scientists are really interested or concerned with what science is from philosophical, historical, sociological, and/or psychological contexts. They do their science because they are curious about the objects and events encountered in the natural universe and want to satisfy their curiosities. However, few analyze the fundamental activities which define science. They remain immersed in what they know and what they do not know within rather narrow areas of study. Several important activities that characterize the scientific enterprise include features proposed by George Gaylord Simpson in 1963. These include:

1) asking questions about objects and events in nature;
2) offering explanations that account for natural phenomena;
3) seeking evidence to determine the validity of the personally offered explanations;
4) presenting the evidence (experiments, logic, observations) which support the explanation;
5) communicating the results and ideas to the established academy of scientists.

These activities portray science as a discipline of action rather than as a body of knowledge with which most scientists accept as accurate. The information that accrues is not itself science but instead the "products" of "sciencing".

Richard Feynman's writings and conference presentations (Feynman, 1964; 1985) often remind us that the real content of science comes from the successes with the above list of activities. Feynman posited three categories of knowledge about the natural world, each with a particular focus. The first of Feynman's foci for science dealt with the aspects of the natural universe about which we are curious but that we do not know. Feynman's second focus dealt with the things we "know," but that are not so! His third focus dealt with aspects of the natural universe of which we are ignorant (we do not even know we do not know).

K-12 and undergraduate science faculty rarely take the time to emphasize the five activities of the scientific enterprise or even consider Feynman's categories of knowledge about the natural universe. These should guide students as the work to understand the natural world. Further, little attention is typically given to technology. Often when it is considered, it is pejoratively called "the applications" of science. In secondary schools it is typically relegated to the industrial arts shop primarily directed to non-college bound students. During the 1950's and 1960's it was consciously removed from the K-12 science curriculum and textbooks because it was NOT science! The only significant emphasis was on the knowledge that scientists had discerned about the natural world. Jerrold Zacharias, architect of the Physical Science Study Committee (PSSC), initiated this narrow focus in 1956 with major National Science Foundation (NSF) support (Zacharias, 1956). The national attempts at reform centered on the major concepts characterizing the natural sciences, namely physics, chemistry, biology, and earth science (listed in the order of perceived importance and attention!).

As the 1990's emerged and the STS efforts internationally matured, there was renewed interest in technology and its role in the education of future scientists and engineers and its ties to science. A simple definition is that technology is a focus on the human-made world using the same activities as those listed above for science. The major difference is the fact that in technology, the end points are generally known in advance and are seen as serving some human need. We know in advance the end we seek. Technology results in tangible "products" and "procedures" while science results in new information and explanations regarding the natural world. When we talk of the human-made world, we know there is a desire for faster airplanes, cooler homes in the summer, better televisions, and more efficient and powerful automobiles. In the case of science we have to take the natural world as it is.

STS as Effective Science Teaching and the National Science Education Standards

Learning from the STS reform efforts and the latest research from the cognitive sciences became central to the attempt to develop and establish National Science Education Standards (NSES) in the U.S. (NRC, 1996). In fact, STS leaders influenced their development over the 1992-96 interim when national consensus was sought. Many in the U.S. see the completed and published NSES to be a blueprint for STS efforts in the K-12 arena. For example, the NSES list nine changes needed in instruction if real learning is to occur (Table 1). These nine changes epitomize the so-called STS approach.

Additionally, the standards resulted in more emphasis on assessment both in terms of establishing that authentic and meaningful learning had occurred, but also as a way of making science education more of a science (i.e., employing the same five activities in education that are used in science). The changes in assessment were seen as more important than defining school programs in terms of specific content (Table 2).

Wiggins and McTighe (1998) helped immensely in developing a new focus on assessment when they assembled research to note that good instruction lies not in the presentation of content (i.e., traditional teaching), but in assessing student learning and coaching students toward

TABLE 1

Changes in Science Education Needed to Accomplish the Visions Central to the NSES (NRC, 1996, p. 52)

Less Emphasis On	More Emphasis On
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 inquiry
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
Maintaining responsibility and authority	Sharing responsibility for learning students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

TABLE 2

Changes in Science Education Assessment Envisioned in the NSES (NRC, 1996, p.100)

Less Emphasis On	More Emphasis On
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well-structured knowledge
Assessing scientific knowledge (emphasizing vocabulary)	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 opportunity to learn
End of term assessments by teachers	Students engaged in ongoing assessment of their work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments

better performance. Their recent work was entitled Understanding by Design. It means establishing goals first then immediately discussing and identifying ways those goals could be assessed to know if learning had occurred. Wiggins commented recently (ASCD, 2005) that educators are paid to coach learners, not to teach content!

In addition to changes in teaching and assessment that STS demands, STS advocates note that the NSES provide a new vision of what defines science content. The NSES Standards define content in eight categories. These include:

1) Unifying Concepts and Processes;
2) Science as Inquiry;
3) Physical Science;
4) Life Science;
5) Earth and Space Science;
6) Science and Technology;
7) Science in Personal and Social Perspectives;
8) History and Nature of Science.

STS leaders would de-emphasize the three classical facets of science content (i.e., physical, life and earth/space) and instead group content in a single category perhaps called "science conceptual understanding." Paul Hurd (1998) has proclaimed that the only places that these traditional disciplines still exist are in high schools and in undergraduate colleges. He maintains that most current science research cuts across several traditional disciplines and that the separation of science from technology no longer makes sense. Contemporary science is completely dependent on technology for its tools. In other words, defining technology solely as the "applications of science is senseless!"

Domains of Science Education and the Six "C's"

McCormack and Yager (1989) have proposed six domains for evaluating science teaching success. These domains do not negate the facets of content that are used as organizers in the NSES. However, the domains indicate varying goals and foci for science teaching and student learning. The domains also suggest a hierarchy for approaching the reforms in teaching that correspond to the ingredients of science itself. Science starts with questions and with many converging to work on and to interpret better the Nature of Science.

Figure 1 is an attempt to illustrate what the NSES and STS educators view as the "domains" for science education. Traditionally only the major concepts are considered and to a lesser extent the processes scientists have used to define the content in schools . The skills scientists use in their work has been advanced as an important consideration in U.S. science education for nearly 100 years. However, they became a focus in the 1960's when the American Association for the Advancement of Science (1965) developed an entire elementary science program around process skills. NSF supported the development of Science - A Process Approach (SAPA) by the identification of 14 such skills as the organizers for school science.

Today over 90% of the emphasis is on the "bulls eye" as indicated in Figure 1. However, the "membrane" around the bull's eye is where primary activity should be concentrated the enabling domains. These are attitude (affective) and creativity (questioning and hypothesizing). However, the even larger domain where most people live, work, and learn is the application domain; the worldview is defined as the societal, historical, and philosophical dimensions of the scientific (and technological) enterprises. Again, humans are involved as analyzers and philosophers of the whole enterprise. Current efforts in science education after the publication of the NSES indicate how optimal learning and personal experiences with science and technology are to be achieved in our modern society.

"The Science Education Pyramid" presented in Figure 2 links six ideas required for meaningful learning that are readily apparent in the STS approach. Just as in both science and technology, science education needs to start with curiosity, i.e., questions and personal interest. Rarely do typical instructional strategies or standard curricula begin with such conditions. Instead they start with content (big ideas) that someone (many times state curriculum guides) agrees are the important ideas to "present to" students.

Creativity is related to curiosity. Most curious people are creative. They ask questions; they seek to answer their own questions; they identify information needed to provide evidence for the validity of their answers. Basically, the more creative a person is, the more he/she questions and relates often in ways that other people see with obvious connections. But, such situations require more debate and dialogue among people.

The third "C" is content but hopefully information that is needed for actions, understanding, problem resolution not just organized information for its own sake. It should develop from activities and situations not as pre-determined givens.

The fourth "C" is constructing meaning. This "C" emphasizes that learning requires mental engagement, meaning making, and linking ideas. Basically it is the idea that the learner must make sense of his/her experiences and information he/she uncovers (Brooks & Brooks, 1993). While teachers can help with those processes, meaningful learning does not follow from teachers demanding that students remember and repeat what is told to them. What is better evidence that real learning for individual students has occurred?

The fifth "C" level is context. This is the situation perhaps identified by a teacher, or an event, often in a local setting. Context is the situation that is defined as the ingredient that enables and encourages mind engagement and real learning in individuals. Without a context created or identified by learners, meaningful learning will not occur. With a focus on context new visions of assessment are identified. Can learners who learn in one context use it in other contexts? This is a perfect way of separating creative persons and ones who

FIGURE 1
Six Domains for Teaching and Assessing Learning

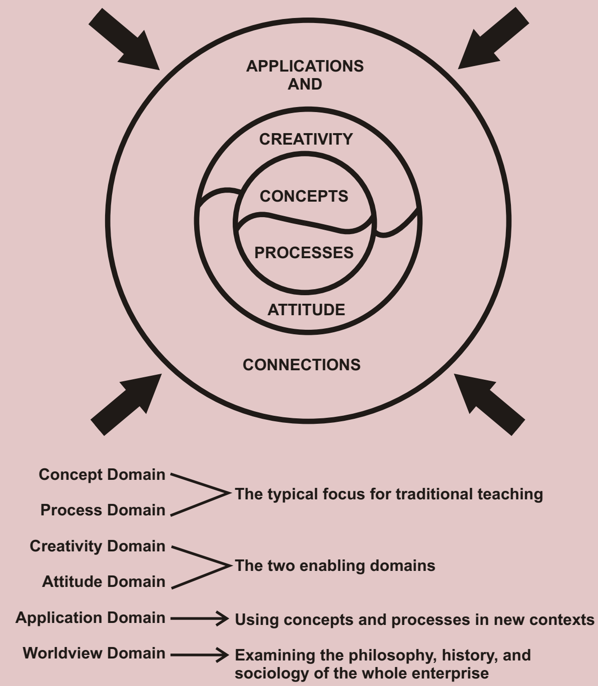
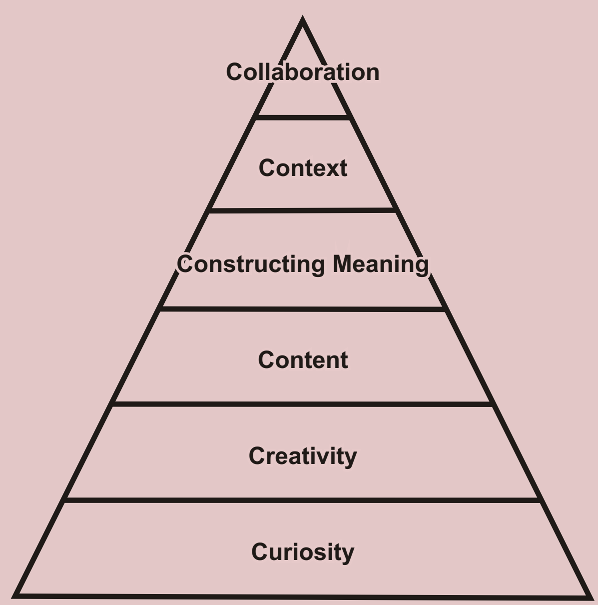


FIGURE 2
The Science Education Pyramid



have really learned from those merely pretending that they have mastered what is in the curriculum. Expecting students to use science concepts and skills in new contexts may be the best evidence that real learning has occurred.

The sixth and final level on the Six "C" Pyramid is collaboration. Can people work together in the classroom, in the community, in the nation, in a global sense to solve the problems which surround us? Collaboration and "connecting" are needed between teachers and students; among leaders, among students; among as many as possible who are interested in the problems of today. This includes Feynman's second facet of science i.e., dealing with things we think we know that are not so. This puts science and technology into a dynamic relationship which requires collaboration, debate, data collection, and evidence sharingall coming together as real problems are resolved which will affect the future.

This "connecting" or "collaboration" level illustrates the advance of science when new ideas need to be validated to become part of the explanations for the objects and events in nature. This level also indicates the current understandings of human learning. It is not something (unlike art, music, and religion) which can be experienced and practiced by individuals. Traditional science teaching is very much like drama when students learn their lines and express them with feeling for the delight of teachers and as ways of impressing other students.

The current NSTA effort to find examples of connecting-collaborating as the top "C" will become the seventh Exemplary Science Program (ESP) monograph in 2009. Some past examples include teacher teams and student teams involved with common problems, possible solutions, and student team attempts to determine the validity of the explanations they advance. They provide all the experiences characterizing science itself! Examples include questions proposed by students and are used to define science programs. For example, Morgan Masters worked with middle school students to replicate a space ship in Chariton, Iowa, which included the whole school and community's efforts to build, test, and actually "Blast Off". It was also exemplified with Joan McShane's effort in Davenport re-directing an environmental unit into a major effort involving and testing nearly fifty brands of toilet paper as a way of learning about many types of pollution problems arising from a student's problem at home with a clogged toilet. A fine example also comes from Jim Kollman in Denison who worked with a chemistry class of future hair dressers who tackled the problem of Ozone Depletion for an entire year. A great example occurred in Gladbrook-Reinbeck with Becky Fish who over the course of an entire year used student observations and questions to frame her kindergarten science class. An example of Becky's students' efforts were the students' observations and testing of composting pumpkins after Halloween over several months with the surprising pumpkin seedlings appearing before the closing of the spring semester (from the PreK-4 ESP Monograph).

Connecting with others with collaborative approaches should be a top goal in education. It is a final test when we evaluate whether or not we have met the major goals for science education as identified in the NSES. The most important goal for education should be the production of scientifically and technologically literate graduates and citizens who are able to work toward an optimal and sustainable global society. These suggestions work when dealing with health issues, a sustainable future, environmental degradation, new energy sources. Whenever possible these issues should be framed as local problems and happenings which are of current importance and personally relevant.

Final Thoughts

What can science teachers do to advance our discipline? Certainly the first step would be to join others with similar concerns. Look for those who propose ideas for resolving problems, or who respond to our curiosities, and enter into debates with those who aspire to be collaborators. Adopt a more scientific approach to teaching by identifying problems, proposing possible solutions, working cooperatively in the school involving other teachers, administrators, parents, and community leaders. We need to identify researchable ideas and work on them. When appropriate, students should be included as partners in all the efforts.

None of us can simply wait to see what happens next; we need to make things happen in our classrooms, schoolwide, within our communities, and beyond our communities. This should result in both the excitement and the reward of being in a collaborative relationship. We could achieve the reforms which have eluded us when we work hard as individuals in concert with others. This would make our professional societies places where ideas are shared and evaluated. Professional societies should not merely be places to go to present information, or to interact or recite answers to questions requiring only memory and repetition. They should be places to share questions, to engage in collaborative acts, and to advance our profession.

Too often teaching becomes a lonely profession where teachers find themselves locked into a classroom with varying student sections appearing all during the scheduled day. There is too little time for Action Research projects, curiosity regarding what might be tried and evaluated. These efforts could make science teaching more of a science including all five of the same ingredients. Some have argued that we will never have a real profession until teachers stop acting like factory workers. The challenge becomes one of ensuring that all teachers have one problem on which they might collect data each day, each week, each nine-week grading period, each semester, and/or each year.

Hopefully Figures 1 and 2 of this article will provide all ISTS members and their teacher colleagues with encouragement to be even more curious and more willing to collaborate and connect in teams to have experiences which mimic the science of science teaching.

Hopefully there will be new teams of science teachers who are ISTS members and who will be anxious to work together in reforming science teaching in Iowa and willing to share evidence for their successes in this Journal and at future ISTS conferences. Iowa can exemplify what is possible and provide more Exemplary Science Programs for inclusion in the NSTA ESP Monograph series. Hopefully there will be several nominations and projects underway and completed for the 2009 monograph.

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