Real Reform in Science Education Takes More than "Stirring the Pot"

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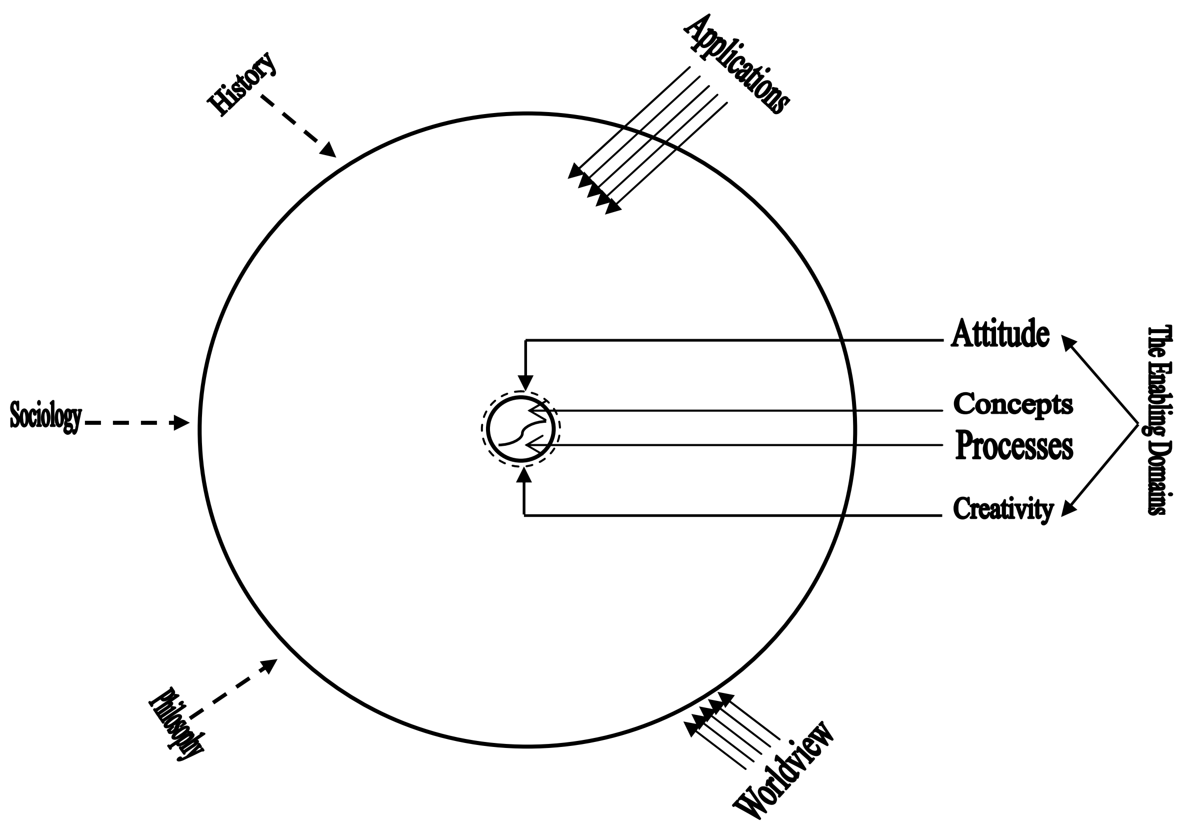
Too often reform efforts in science education classrooms consider only the major concepts that define what is to be taught with too little attention to how it is taught! Too often assessment is based on student performances in class and on examinations that measure the retention of information gained from teacher talk, class recitations, and textbook coverage. The 1996 National Science Education Standards (NSES) portray science as human endeavor, an indication of what should be done in science classes, and the ways science teaching should be conducted. One example of needed reform advocated is that Science CONTENT is described with eight distinct foci. The eight are listed in the order they appear in the Standards which also suggest an organizational scheme for school science. These facets are: 1) unifying concepts and processes in science; 2) science as inquiry; 3) physical science; 4) life science; 5) earth and space science; 6) science and technology; 7) science from personal and social perspectives; and 8) history and nature of science.

The last three of the eight have been given little attention over the past 30 years. Basically the reforms were newer looks at understanding the typical science disciplines characterized by the work of scientists and the "process" skills they use to develop the explanations accepted and suggested for use in educational settings. Two reform efforts during the late 60s prepared for elementary schools indicate a continuing problem. The Science Curriculum Improvement Study (SCIS) was organized around major science concepts. A project called Science: A Process

Approach (SAPA) focused exclusively on fourteen process skills. In addition to merely listing the important science concepts and process skills which are often used to define and plan school offerings, the NSES introduced a major new approach and used it as the first facet of content, namely the "unification" of concepts and processes. Both are viewed as "domains" for teaching and learning science in the Yager and McCormack model (1989).

Figure 1: Teaching and Learning Domains and their use in Promoting More Success to Meeting the Goals that Frame the National Science Education Standards



Few criticize concepts and processes comprising the two domains and few expect any other foci for school science programs. The "unification" of the two was to be done by individuals, including teachers and to do more than merely outlining concepts and processes to be taught separately from textbooks or state curricula.

Once concepts and processes were unified, they were to represent the world created, known, and used by practicing scientists; they were also organized as three of the NSES discipline categories, namely physical, life, earth/space (facets number 3, 4, and 5). Such a classification of these disciplines has been a focus of most school programs for nearly a century. There have been many attempts to promote interdisciplinary courses, K-16. Many of these are often found in elementary schools and middle schools. Surprisingly, such approaches are now being tried in many universities. The place where little change seems to occur is in high school science for college preparation for college and for undergraduate offerings in colleges. The one innovation with the discipline categories was the joining of physics and chemistry into "physical science" – a recommendation that has been ignored by most high schools and colleges. But, the three discipline categories certainly assume that the "unification" of concepts and processes has been accomplished!

Inquiry was listed as facet #2 in the Standards which has attracted more attention since its use in the early 60s as an obvious and important form of content as well as suggesting needed teaching strategies. Inquiry (facet #2) has now become a “religious” term accepted by all. It is now used to describe textbooks, teaching technology, and a major focus for all state curricula. Inquiry has been central to all reform in science education since its inclusion in the NSF-supported projects of the 60s and 70s. Joseph Schwab (1963) defined it as “What Science Is” – and to capture more attention he spelled it “enquiry”! But, many science educators want to add the word “science” as an adjective when referring to “scientific investigations”. It alone is a word with no unique meaning – something that many science educators applaud! Do students even feel ownership and use of such content as something designed to affect their own lives? The NRC, in its Inquiry volume, list five essential features of inquiry. They are: 1) Learner engages in developing scientifically oriented questions; 2) Learner gives priority to **evidenc**e in responding to questions; 3) Learner formulates **explanations** from evidence; 4) Learner connects explanations to other scientific knowledge; and 5) Learner communicates and justifies explanations (NRC, 2000, p. 29). For many people these ESSENTIAL features are ignored. Some science educators maintain that the “essential” features cannot be attained.

The NSES recommend three other new foci for CONTENT (often also indicating broader uses of inquiry in the discipline categories). These are also included in the Yager-McCormack Domain Model. Unfortunately, conflicts remain concerning these three newer areas of CONTENT. Also, conflicts regarding them and/or ignoring them also is a problem when looking at the four goals that are recommended as organizers for school science in the NSES. These four goals are listed to frame what should go on in science classrooms. They should be central in achieving the current reform efforts with students. These goals include students who: 1) experience the richness and excitement of knowing about and understanding the natural world; 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, understandings, and skills of the scientifically literate person in their careers. The first goal was to ensure that each student has personal "experience with the richness and excitement of knowing about and understanding the natural world". It was to assure that every student has experience with "doing" science as opposed to following directions from teachers, textbooks, or curriculum guides (even once a year??)! It was/is a major departure to assume that all students should experience the essence of science for themselves. This is again where the Essential Features of Inquiry should be reviewed!

Many now indicate that most students graduate from high school without a single real experience with "doing" science (or dealing with its features, with the five essential features of inquiry, with any applications of science in new settings). The first goal indicates that real science should be approached in more meaningfully ways with students as major players. The final goal was to prepare students to increase their economic productivity through the use of the knowledge, understandings, and skills of the scientifically literate person in possible careers. This is often included as a desired outcome – but it is hard to measure for most K-12 enrollees at a particular grade level in courses called "Science".

One of the first new content facets is the inclusion of technology (the human-made world) in addition to the natural world It is also important that there was one word added, namely an "and" for appropriate/desired CONTENT; it is listed as science and technology! This is a major reversal from the reforms of the 1960's when Zacharias – the architect of the first of the "alphabet" reforms (PSSC Physics) -- proclaimed that all technology should be eliminated from K-16 science "because it was not science"! He argued that including technology (the use of concepts and processes to produce usable devises) was appropriate only for use in special fields (such as industrial arts for non-college bound students) but not science for the college bound. Even though technology was attractive and interesting to most students, it was not to be a part of the school science curriculum. The NSES seek to alter this and to openly promote the study and use of technology in school science programs. This is where engineering and health (as well as environment and energy) can serve as foci!

Another new facet of content included in the NSES as CONTENT is science for resolving personal and societal problems. This content was to be a way of meeting goals 2 and 3 of the NSES reform efforts. It can be an organizer for science study – a reason for learning the "unification" concepts and processes. This 7th facet of content implies student involvement, use of community experts, ties to informal science, service learning, and actual problem resolutions. Some suggest use of "projects". But, too often these become exercises, ideas for students to follow -- where answers are already known. This content facet aims to put students in the roll of asking questions, proposing answers, seeking evidence for the validity of the answers, and using the ideas in problem resolution. This learning is demonstrated in its use and action in the school and the larger community – instead of how well information is remembered or a particular is skill demonstrated. New "Contexts" are too often missing for both actions. They need to come from students – not teachers or books! This facet of content must be defined by students as well as the techniques tried for resolving the personal and social issues. The results can help determine if students really learn, understand, and use what comprises school science.

As mentioned earlier, Yager and McCormack originally proposed in 1989 five domains for approaching needed changes in CONTENT which would entail different reforms that would change teaching, curriculum, and assessment of learning. Figure 1 (See page 3) illustrates their proposed domain structure. The Worldview Domain related directly to the 8th facet of science content, namely "history and philosophy of science". The Six Domain model is suggested as important for science education leaders and researchers. It is a way to focus on the features of the NSES reforms that go unnoticed and/or non-considered in most states and schools and by many education leaders. Too many remain enmeshed with the science discipline-based concepts and to a lesser degree the process skills that scientists have used as they define curriculum and instruction for use in classrooms. Nearly all the innovative reform ideas indicated by the NSES CONTENT facets number 6, 7, and 8 are usually ignored.

The Yager-McCormack model does include science processes and concepts in a central position. But there was the admonition that this "bulls-eye" version is a small place where scientists work and act (perhaps involving only 0.00004 percent of the total human population). And yet typical school programs focus attention exclusively on the "what scientists agree to be known and accurate" and to a lesser degree "how they know" – ignoring the problems and the time it takes to get new ideas accepted by the whole scientific establishment – let alone the whole of society.

The science concept and process ideas need to be enlarged. Two Enabling Domains surround the "Bulls-eye model"; they are Creativity and Attitude. Both of these domains represent what all students have – even before entering schools. And, yet much evidence exists that indicates both of these domains worsen the longer students are enrolled in typical science courses K through 16 (Yager, Choi, Yager, & Akcay, 2009; Yager, Ali, Hacieminoglu, 2011)! Literature reviews reveal that a steady decline in positive student attitudes concerning science are observed as students progress from primary through secondary schools (Cho, 2002; George, 2006, Hacieminoglu, Ali, & Yager, In Press). In other words, the more students study science in school, the less positive are their attitudes and their creativity levels as well.

Carl Sagan (NRC, 1998) has pointed out that all humans are unique in their wonderment about the natural world around them. They are full of questions and awe! Their curiosity seems endless; they have fun learning on their own. Recent research reports indicate that the human brain is at work responding to the natural world while still in the mother’s womb. We cannot afford not to focus on attitudes and creativity. They should be enhanced as ways to make reform efforts more successful. That is why we label them the “Enabling Domains”!

In one sense the Enabling Domains are like cell membranes controlling what goes in and out of the concept and process domains as well as for its uses in the application domain where nearly all humans live and work. There can be no science if there are no questions, no curiosity, and no interest in learning more about the natural universe, and/or the advances in technology that can be used for further explorations of the universe designed to improve human existence. Education may need to focus more on such explanations and questions as well as needed technology for dealing with them.

The research is clear regarding creativity and attitudes. They can both be improved and used in other contexts with different teaching and with attention to each. This is where reforms should begin and end – not in a new construction of the same old constructs of curriculum -- which are based on what scientists know and the skills they have used to develop this "knowing".

Some new efforts have been tried where students (K-16 levels) begin their study and involvement with applications of science and technology – which lead them to analyses of the important concepts and processes needed. Some teacher education programs have introduced a whole series of application courses to match the traditional discipline organization of high school and college offerings (Hakan, 2010; Hakan & Yager, 2010). For the most part these education "offerings" ignore the use of the concepts and skills taught for their own sake.

A sixth domain of the Yager-McCormack model (added after the first publication in 1989) was the Worldview Domain. It remains a major effort for many interested in the philosophy of science, its history, and the sociology of science. It is viewed by many as a new discipline and difficult merely to add to typical science courses. But, many teacher education programs are adding courses in the philosophy, history, and sociology of science. Some call these offerings the Social Science of

Science. Many use the term Socio-Science! Many like this new view of school science. Some even include it as a major learning domain but proceed to teach it like traditional school science, i.e., didactically. Unfortunately, however, typical school and college science programs have changed little. In fact, we still have critics arguing that this Worldview of the science and technology efforts is an echo of Zacharias' earlier comments in the late 60s, namely "these views are not Science"! Nonetheless, it is a look at what science is, has been, and continues to be. This is something with which every science teacher, science education researcher, and educational leader should be aware and involved. Real reforms are difficult to achieve! The research team involved with Project 2061 suggested that real change in schools would not be achieved before the year 2061 – indicating it will take 75 years – the lifetime of typical humans to result in real educational change.

Members of current research and teaching organizations have been invited to interact with each other about real reform ideas as outlined here. Use of the NSTA Exemplary Science Programs (ESP) is recommended as a source of information where current NSES reforms have been tried and found to be successful in meeting goals and preparing for life outside of schools. The first eight of the NSTA ESP Monographs include: 1) Exemplary Science in Grades PreK-4; 2) Exemplary Science in Grades 5-8; 3) Exemplary Science in Grades 9-12; 4) Exemplary Science: Best practices in Professional Development; 5) Exemplary Science in Informal Education

Settings; 6) Inquiry: The Key to Exemplary Science; 7) Science for Resolving Personal and Societal Problems; 8) Preparing for Careers in Science and Technology. All of the ESP series has been completed with involvement of the National Science Education Leadership Association (NSELA).

Too many continue merely to "Stir the Pot" with new efforts to produce teacher-proof curricula and new pathways to achieve the old goals and prescribed curricula. We need more who can practice the visions, logic, and features of science teaching; i.e., science a way of exemplifying science itself. This means investigating ways where more positive results can be gained with direct experiences with science itself (Goal #1 of the NSES) should be emphasized – perhaps as much as 90% of the time and efforts in all K-16 science offerings. These efforts would also include ways of meeting the first goal! This should, however, not be construed as recommending less consideration of the other three goals!!

We can do without so many merely "stirring the same old pot"! Instead we need more building of new pots and seeing what can be accomplished with them!! We need more experimenting with the ingredients used and tried in the pot! The NSES provide ideas for new ingredients! We need more who can stir while also adding ingredients and the accomplishments of new successes with more learning and more who attain and can use the NSES goals!! Others work to add new ingredients to the pot. But, do they always result in more positive outcomes?

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