The dilemma for secondary science teachers:
The High Road (National Science Standards) or the Low Road (High Stakes State Tests)

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Introduction

Robinson (1968) in *The Nature of Science and Science Teaching* argued for the need to change the way science is taught, providing an educational experience similar to the way scientists go about doing science. He explained the change that occurred in the discipline from the nineteenth century to the twentieth century and how this change has been represented in education.

> Nineteenth century science was characterized by an emphasis upon accumulation of data, the classification and description of it, and by an emphasis upon mechanistic modes of interpretation. These modes of thought supported a world view depicting a finite, static, homocentric universe, harmoniously arranged in a hierarchical order. But during the late nineteenth and early twentieth centuries, the pathways of scientific thought departed from these emphases….These revolutionary changes in scientific knowledge were not immediately accompanied by a parallel shift in instruction in the sciences.…The science curricula in the schools have not…reflected the changing nature of scientific knowledge; instead they have reflected the approaches and methods of earlier science (Robinson, 1968, p.5)

Many changes have occurred in science education, but the 19th century style of teaching Robinson described in 1968, is still dominant. Many students leave science classrooms with a finite and static view of the world. Robinson later talked about the wealth of new knowledge being discovered in science and how more knowledge will continue to be discovered as technology advances. The problem, according to Robinson, will not be the growing amount of knowledge, but rather individuals' ability to handle it. A great challenge for science education is to keep up to date with the new information. Science content often becomes outdated in the amount of time a text book is published (Robinson, 1968). Understanding the nature of science itself should be emphasized in schools rather than the content, which may become out of date by the time students end their school year.

The NRC in 2000 (p. 14) states concerns similar to those expressed by John Dewey as early as 1909:

> Science teaching gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind. Science is more than a body of knowledge to be learned; there is a process or method to learn as well (Dewey, 1910).

Inquiry-based Learning

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to activities in which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Science Education Standards, p.23). An inquiry-based science classroom allows students to take control of their learning by giving them open-ended questions to solve and metacognitive scaffolding (Shimoda, White, & Frederiksen, 2002).

Linn and Clark (1995) observed that on many occasions students have ideas about science that are similar to what scientists at one time believed. It is important for students to go through the same processes that scientists went through and account for the inadequacies of their beliefs. If students are able to realize that their current notions are unable to explain a particular phenomenon, they will re-think and revise their thinking. Teaching science directly from the textbook goes against the nature of science itself. Textbooks tend to mask the processes of scientific discovery and inadequately explain the many conflicting observations and provide students with an inaccurate picture of how research is done (Linn & Songer, 1993). In order to effectively teach science through inquiry students should be able to first explore or “mess about” with a particular topic. The terms and principles related to that topic should be presented only *after* the exploration period when the students need this information to reconcile cognitive dissonance; when students perhaps realize their ideas cannot completely explain the problem. Students begin by constructing a model strictly from their observations. As students’ thinking evolves, they begin to refine their model when it is inadequate to explain the topic; this thinking, testing and refining process continues until their model can explain a range of topics (NRC, 2000).

The idea of inquiry-based learning as a successful way to teach science is not new. Piaget (1958) thought that scientific inquiry would result from a variety of experiences, and once learned could be applied across science disciplines (Linn & Clark, 1995). Cognitive Constructivism, a curriculum paradigm supported by Vygotsky (1978), advocated that reality is individually constructed, that “the world is knowable by experiencing and applying key skills and concepts” (VanTassel-Baska, 2002, p. 5). Constructivism also stresses that the learner needs both individual and social activity to construct meaning (Woolfolk, 2001). These opportunities, however, are not widely available in the typical classroom. White and Frederiksen (1998) reported that many teachers find the inquiry approach very challenging and time consuming, and that they lacked adequate resources to do it well. Recently, researchers have argued that inquiry-based learning is more effective when supported by educational technology, such as computer simulations and modeling tools, because it allows for more opportunities for students to participate in open-ended learning environments where they can manipulate variables and engage in scientific inquiry (White & Frederiksen, 1998).

White and Frederiksen (1998) hypothesized that younger and lower achieving students have difficulty with science because they cannot construct conceptual models of science concepts or are unable to monitor and reflect on their studies. To address these learner deficiencies, they developed the *ThinkerTools Inquiry Curriculum* to allow students to test their understanding about the nature of scientific knowledge and learning (White & Frederiksen, 1998). They concluded that the inquiry approach was beneficial for students from many backgrounds and ability levels. They determined:

> The best way for students to understand the epistemology of science is to engage in practices that involve that epistemology, rather than being told about it. The knowledge they develop from reflecting on their own practices as a scientific community should enable them to understand better the history and philosophy of science as well as to evaluate public policy debates where models and results of science play a role. (p. 74).

Constructivist theorists also maintain that learning should take place in situations where it will be applied later; that individuals will construct meaning for something based on their own experiences and beliefs (e.g. Hannafin, Hannafin, Land, & Oliver, 1997). For this reason, learning about something in real life situations is extremely important for students if they are going to apply the knowledge they are learning to solve future problems. Inquiry-based learning activities require students to solve real life problems.

Reform Efforts and Standards in Science Education

> The 'basics' of the 21st century are not only reading, writing and arithmetic. They include communication and higher problem-solving skills, and scientific and technological literacy—the thinking tools that allow us to understand the technological world around us. These new basics are needed by all students—not only tomorrow's scientists—not only the talented and fortunate—not only the few for whom excellence is a social and economic tradition. All students need a firm grounding in mathematics, science and technology. (National Science Board, 1983, p. v).

Over the past couple of decades, organizations have developed plans to help improve the quality of the science, mathematics, and technology education in the United States. In 1985, the American Association for the Advancement of Science (AAAS) developed Project 2061, a plan to make all American high school students literate in science, mathematics and technology by the time they graduated from high school. The goal was to make all students who were entering high school in1985, the year Halley's comet could be viewed from Earth, scientifically literate until Halley's Comet returned 76 years later in 2061 (Hoffman & Stage, 1993). In 1993, the AAAS established a set of benchmarks in science, mathematics, and technology, which were intended to be recommendations and guide points for what students should know at different grades in order to be on track to become scientifically literate adults (AAAS, 1995).

In 1989, President Bush and the United States' governors created the *National Educational Goals* in 1989 (Trowbridge, Bybee, & Powell, 2000), which proposed the idea of national standards for particular subjects. In 1995 the National Science Teachers Association (NSTA) and the National Research Council (NRC) developed the National Science Education Standards (NSES) (Trowbridge et al., 2000). More than 18,000 teachers, school administrators, parents, curriculum developers, college faculty, administrators, scientists, engineers, and government officials (National Academy Press, 1998) contributed to the NSES.

The NSES were set up for several reasons: to be a goal for what students should learn and what science programs should be like, to serve as a marker to judge existing science programs, and to serve as criteria for future science programs (Trowbridge et al.). The NSES tried to move away from a science classroom that emphasized the facts of a science discipline, towards a classroom that stressed understanding of processes and how science works. Students, it was hoped, would take a more active role, both mentally and physically, in their science education.

At the heart of the NSES is the role of inquiry in science. The NSES define scientific inquiry as:

> The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Science Education Standards, p. 23). (NRC, 2000, p. 1).

The NSES makes a distinction is drawn between *learning* science, learning *to do* science, and learning *about* science (NRC, 2000). Learning science should feed off of the natural curiosity of students and maintain their interest in science. The NSES also emphasize large unifying concepts that go across all disciplines and all levels of science. Instead of learning lots of disjointed facts, as is common in many traditional science classrooms, the standards stress the importance of teaching the broad concepts that cover all areas of science. There is also an emphasis on the interconnectedness between science content that is learned in the classroom and real-world applications. The NSES attempt to stress the importance of science in students' day-to-day lives and increase their interest in the subject. They are voluntary and indicate what is important and should be covered in schools. The NSES are considered to be "national" because they were written by a representative group and are to serve as a model for state and local education agencies (National Academy Press, 1998). The goal of the NSES is to develop a community of scholars working with a body of knowledge, science. The NSES are not meant to be used as curriculum guides.

In 1995, the state of Virginia began a phased in a reform program that set up standards in public education in Virginia. The Virginia Standards of Learning (http://www.pen.k12.va.us/VDOE/superintendents/SOL/foreward.pdf) were intended to establish minimum requirements for each grade level or course; schools were encouraged to augment the standards wherever possible. The Virginia Standards of Learning (SOL) are based on the NSES, but unlike the NSES, list specific discipline content that should be covered in all Virginia State schools. This content was consistent with what the NSES believed to be important for schools to cover (http://www.pen.k12.va.us/VDOE/Instruction/scienceSOL/comparov.html). The NSES and the Virginia SOL are similar in both the concepts that they emphasize and in the role they advocate students take in their education.

The Accountability Movement and High-Stakes Testing

At the same time the education and science communities were calling for reform in science education, strong political movements were influencing education in unprecedented ways. The latest example is the “No Child Left Behind Act” (2002), which has become the Bush administration’s primary blueprint for educational policy. This act is organized around four main points: accountability for results, an emphasis on doing what works based on scientific research, expanded parental options, and expanded local control and flexibility (http://www.nclb.gov/next/overview/index.html). It requires that states measure student achievement each year and schools and teachers are now held accountable for the achievement of their students. High-stake tests have been established in many states to measure and track students’ progress. In Virginia, tests that are based on the SOL were established in the spring of 1998 (http://www.pen.k12.va.us/VDOE/Instruction/VASOLtudy.pdf). Students take the Virginia SOL tests at the end of 3rd, 5th, and 8th grades and at the end of certain courses in high school. The state can identify exactly which content areas are weak and which schools are at risk.

Both the NSES and Project 2061 were established to improve the nation’s science education; to move it away from the traditional fact-based curriculum to one that stressed the nature of science. Likewise, the Virginia SOLs also were established to increase inquiry and understanding in Virginia schools. However, states also have to respond and abide by the NCLB mandates, i.e., demonstrate the efficacy of schools, teachers, and students and here lies the problem. Whitehead (1929) argued that "[N]o system of external tests which aims primarily at examining individual scholars can result in anything but educational waste (p. 13)" (quoted in Oliver & Hannafin, 2001, p. 28). For strictly political reasons, Virginia has to respond to the national demands for high-stakes tests that will ensure accountability. These tests, however, discourage what the NSES, Project 2061, and the SOLs were originally established to achieve.

Although the Virginia SOLs are consistent with the reform themes set forth in both Project 2061 and the NSES (Czerniak, Lump, Haney, & Beck, 1999), the standardized tests designed to measure the standards have been criticized by some administrators, teachers, and parents as inadequate at measuring those higher-order outcomes. Based on the lead author's personal experience as a first-year high school science teacher, many teachers now focus narrowly on the content that is outlined in the Virginia standards because that is what the test is based on. Teachers are now reluctant to delve more deeply into a particular topic because of the pressure to cover the content. During my teaching experience, I encountered many teachers who lament the fact that they can no longer do certain activities or labs due to lack of time. They feel pressured to concentrate just on the content their students need for the end of year test.

It could be that the SOLs were introduced to the teachers without a full rationale or adequate training in how to teach with them. As mentioned earlier, the SOLs were established with inquiry in mind. The first goal of the science SOL is to "develop and use an experimental design in scientific inquiry" (http://www.pen.k12.va.us/go/Sols/science.html, p.4). However, strategies to effectively include the standards in innovative and inquiry-based learning environments have been modeled or taught to all teachers. From my observations in the schools, I get the sense that teachers do not completely understand the standards, and coupled with the pressure of high-stakes testing, think of them as mere content that needs to be covered. Many teachers have reduced the number of hands-on activities and labs from their classrooms and replaced them with lectures that provide the students with disconnected facts ironically, we argue, are causing a greater disinterest in science among students. In the next section, we will examine this disconnect more closely.

The Standards – Assessment Disconnect

Linn and Clark (1995) described assessment as "any systematic information about students that informs educational decision making" (p. 142). According to the NSES assessments help to define, in a measurable way, what should be taught by teachers and learned by students (NRC, 2000). The NRC (2000) claimed that there are three major learning outcomes for inquiry-based science teaching that should be assessed: Conceptual understandings in science; abilities to perform scientific inquiry; and understandings about inquiry. Traditional standardized tests, we assert, do not accurately measure these three NRC outcomes. We are not suggesting that these tests only measure lower-order skills; we do argue however, that they are better suited to assess such skills. Historically scientific information has been viewed as separate from problem solving abilities (Linn & Clark, 1995), and have been assessed separately. Problem solving includes "any dilemma, question, or situation that requires linking and combining information to reach a conclusion" (Linn & Clark, 1995, p. 142-143), and multiple-choice format tests simply cannot adequately assess these skills.

It is very challenging to construct a multiple-choice standardized test that accurately assesses the goals of the NSES. Koyna (1994) argued that standardized tests could not accurately assess inquiry-based science programs. Further, Linn and Clark (1995) found that tests that emphasize recall of factual science information systematically favor students of high ability and reinforce the idea that only a select few have the ability to succeed in science classes.

As mentioned earlier, both the NSES and the VA SOL purport to encourage inquiry-based learning in science education. Therefore, the SOL tests should assess inquiry skills and higher-order thinking skills. To confirm this, we analyzed the questions in the 2002 VA Earth Science SOL test to determine the level of each question. If many of the questions empahsize recall of factual content, it would make sense that teachers emphasize that content in their classroom instruction. If, however, the questions measured higher-order thinking skills, then the teachers should be stressing the inquiry-based instruction recommended in the NSES and VA SOL.

To analyze the tests, we used a taxonomy table that looked at both the Knowledge Dimension and the Cognitive Process Dimension for each question (Anderson, 2003). The Knowledge Dimension consisted of four types of knowledge: factual knowledge—the basic elements students must know to be acquainted with the discipline or solve problems in it; conceptual knowledge—the interrelationships among the basic elements within a larger structure that enable them to function together; procedural knowledge -- how to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods; metacognitive knowledge -- knowledge of cognition in general as well as awareness and knowledge of one's own cognition (Anderson, 2003, p. 34). In examining the 50 questions on the target SOL test, we found 23 factual knowledge questions, 16 conceptual knowledge questions, and 11 procedural knowledge questions. We did not identify any metacognitive knowledge questions on this test.

The Cognitive Process Dimension consisted of six cognitive processes: *remember*—retrieve relevant knowledge from long-term memory; *understand*—construct meaning from instructional messages, including oral, written, and graphic communication; *apply*—carry out or use a procedure in a given situation; *analyze*—break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose; *evaluate*—make judgments based on criteria and standards; *create*—put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure (Anderson, 2003, p. 32-33). Of the 50 questions, we found 15 remember questions, 23 understand questions, 8 apply questions, 3 analyze questions, and 1 evaluate question. We determined there to be no *create* questions on this particular SOL test.

It was difficult to fit many of the questions in a distinct category. Some of the questions could have been placed in two categories depending on how students were taught about the specific content being tested. For example, one question specifically asked, “which layer of the sun is the most dense?” If the teacher had covered this material in class it would have been simple recall that the core is the densest section of the sun. However, this could also be considered a higher-order test item if for students who applied knowledge that the core of the Earth is the densest part of the Earth, or that because the core of the sun is the inner most section of the sun, the most pressure will be exerted on it, and therefore it will be the most dense region of the sun. If students understand that concepts covered under a particular topic also relate to other topics, they can often apply that knowledge to questions about topics they might not have covered in class.

The problem, however, is that a lot of the questions are meant to measure students’ ability to reason scientifically but because of the nature of the multiple-choice format, end up encouraging the deconstruction of knowledge into discrete “memorizable” chunks of information. For example, consider the following test item:

Even though the Earth's inner core is hotter than the liquid outer core, it is still solid because—

A. the heat rising from the inner core is melting the outer core.

B. there is more water in the outer core and it dilutes the materials

C. the outer core is farther from the center, and there is less gravity holding it together

D. the pressure from all of Earth's layers keeps it in a solid state

The intent of this item is to measure whether students could infer that the answer is D, since the core of both the sun and planets are solid and that the reason they are solid is because there is so much pressure exerted on the core. However, if students learned these facts all separately, they will need to have memorized many discrete facts to answer this question. If they are taught to understand the relationship between science concepts and to apply their knowledge, they will be able to answer questions on the test even if they do not know the facts being tested. The fact that these questions can be viewed as lower level comprehension or recall questions encourages teachers to teach in this didactic fact-based manner.

There were no metacognitive questions on this test, but research shows that students' reflection on their own work is crucial to their understanding of the scientific process (White & Frederiksen, 1998). Self-monitoring is also very important for achieving an integrated understanding (Linn & Songer, 1991). It is through self-monitoring that students can assess how they are doing and then use the feedback they receive to adjust their activities (Linn & Songer, 1991). If the reasoning behind the answers students give and the processes involved in determining the answers are not tested, teachers are not going to spend time helping students develop these skills. Instead, they will spend the extra time on trying to cover more content that will be assessed on the SOL tests. If this is the case and the metagcognitive process is left out, an enormous part of the scientific inquiry process will be missing from school curriculums. Even though these processes are central to the entire standards movement, since they are not directly tested teachers will most likely not even address them in their classrooms.

Conclusion

The NSES, Project 2061, and the VA SOL all called for science reform and encouraged inquiry-based classrooms. Why then is the learning of science still dominated by the didactic style where facts are emphasized and the nature of science is pushed to the background if it is addressed at all?

We believe that there are several factors that contribute to this disconnect between what the standards call for and what is actually happening within the classroom. First, there is a lack of teachers' training and support. Because the inquiry approach is not widely used and modeled, many teachers are unsure how to implement it into their classroom. There needs to be more professional development and modeling of this style of instruction. There also need to be more support systems in place in the school to help teachers who are trying to employ these teaching techniques in their classrooms.

Second, our education system is structured to support the traditional teacher-based paradigm. The NSES and Project 2061 advocate for students to see the interconnectedness between the science disciplines and the interdisciplinary nature of all school subjects. From the beginning, however, many students are led to believe that the sciences are distinct disciplines. In most high schools for example, students start out taking Earth Science, then proceed on to Biology, then Chemistry, and their culminating experience is Physics. The science disciplines are usually not connected from one discipline to another. Even though the NSES stress the importance of the unifying concepts in all science disciplines, these are generally not taught and are not linked together among sciences. And in the earlier grades, where opportunities to make interdisciplinary links are perhaps more abundant, there is sometimes a lack of teacher knowledge about the sciences. Many elementary school teachers do not have a firm background in science (Rutherford & Ahlgren, 1990), which makes it very difficult to link science disciplines together and even harder to link science to other subjects. The way our system is set up right now, students will often times forget what they learned the year before as they proceed onto the next year's science course, so if the link between all of the science is not stressed, the interconnectedness will not be realized. Having science courses divided up in this manner, reinforces the idea that the sciences are separate disciplines before the students even begin to learn about the subject. Also, because teachers in all subjects are under such time constraints with the amount of information they are required to get through, they feel there is rarely time for interdisciplinary work.

We believe that there needs to be one integrated system that shows the interconnectedness of the subjects from the beginning of a student's career. Schools tend to be separated into segments from the very beginning of education. In elementary school there is typically a time for math, a time for language arts, a time for science, and so on. In junior and senior high school it gets even worse because the students have to switch classrooms for every subject. This disjointed nature of school reinforces the notion that the subjects are not related. The goal of education is to prepare students for the future and to teach them to think. Life is not divided into distinct segments, so why should schools? We need to prepare students to apply all areas of schooling to solve problems in the real world.

Third, and most importantly, the high-stakes standardized assessments we believe are discouraging teachers from trying out new innovative teaching techniques. To the extent that

Virginia’s assessments are representative of other states’ efforts, the issue is potentially critical. These assessments allow, even encourage, teachers to focus on simple recall, which leads to didactic, fact-based classrooms. It is predictable that when high-stakes tests are involved, teachers will revert to what they feel comfortable with, which in most cases is the traditional teacher centered classroom. Students leave their science classes knowing a little about a lot of concepts, instead of having a depth of understanding about a few concepts. There is a limited amount of time to cover the vast content in the curriculum, and since the skills involved with how science is done in the classroom are not tested, they are cut out of the curriculum in order to make room for more content.

According to Hannafin et al. (1997), “for any learning system, root foundations need to be aligned in order to maximize their coincidence and shared functions” (p. 106). In order for inquiry-based learning to be effective, the learning system needs to match up in order to accommodate and support it. The lack of congruence in our learning system is a problem right now and one of the reasons there is resistance to employing inquiry-based instruction in our classroom. The standards are ambitious and noble, but the way we assess them threatens to render them irrelevant.

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