

Looking Inside the Classroom: Science Teaching in the United States

Findings from the *Inside the Classroom Study* suggest that the key is not the particular instructional strategies that are used, but rather engaging students in ways that lead to their conceptual understanding.

For the past few decades, the nation's attention has focused with varying intensity on the quality of science education. Out of concern that an overemphasis on science vocabulary had led to a misrepresentation of the nature of science, the National Science Education Standards argued for more attention to inquiry as the hallmark of good science instruction (National Research Council, 1996). However, there continue to be differences of opinion about the extent to which student inquiry should be directed by the teacher and/or instructional materials, with some accepting guided discovery as appropriate inquiry, and others defining inquiry as students devising their own approaches to answering their own questions. One line of reasoning is that given the time required, if the curriculum includes a great deal of open inquiry, students will not have an opportunity to learn many important science concepts. In some cases, use of hands-on activities has been equated with inquiry; others note that hands-on without minds-on is hardly scientific; while still others point out that computer simulations and even thought experiments may also count as inquiry. Although there is not always agreement about the best instructional strategies, there does appear to be consensus that the goal

of science instruction is teaching for understanding, not only understanding of science disciplinary content, but also understanding the centrality of inquiry in science.

Factual information is important as a means, rather than as an end in itself, for students to construct deep understanding.

Understanding is defined generally in the literature, as “a matter of being able to do a variety of thought-demanding things with a topic—like explaining, finding evidence and examples, generalizing, applying, analogizing, and representing the topic in a new way” (Perkins and Blythe, 1994). It is also “the capacity to use current knowledge, concepts, and skills to illuminate new problems” (Gardner and Boix-Mansilla, 1994). These definitions are usually not the focus of debate. Divergence in the science education community centers on the process of how students attain these understandings.

The most prominent theories on how students develop understanding are based on the idea that learning, in children as well as in adults, is active (Bransford et al., 2003). Piaget suggested that learning involves the acquisition of organized knowledge structures ... “[and] the gradual acquisition of strategies for remembering, understanding, and solving problems” (Bransford et al., 2003). Vygotsky stressed, among other things, the importance of social interaction for learning (Greeno, 1997). Ausubel (1967a) suggested that regardless of whether one experiences “reception learning” (the acquisition of information through lecture, print, image, etc.) or “discovery learning” (through which the principal content must be discovered by the learner), the learner must be able to relate new information to existing cognitive structures in order for learning to be meaningful.

These theories have vast implications for instructional practice. Since students clearly enter the classroom with knowledge and ideas about the world (Bransford et al., 2003), teachers must identify and evaluate student preconceptions and incorporate this understanding into instructional decision-making (Ausubel 1967a, 1967b; Bransford et al., 2003; Carey



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and Smith, 1993; Tytler, 2002). Under the right conditions, students integrate these ideas with new concepts and information and arrive at a deeper level of understanding, what Ausubel (1967a) termed, meaningful learning. Science teachers are challenged on a daily basis with understanding student preconceptions and creating the “right conditions” for meaningful learning of science concepts to occur.

Science instruction needs to be contextualized for students. Factual information is important as a means, rather than as an end in itself, for students to construct deep understanding. Facts are essential, but without a broader framework, they lose their power. Similarly, when teachers facilitate students’ inquiries or investigations into a topic, it is important that those experiences be meaningful, relevant, and situated in a broader conceptual framework (Ausubel, 1967a, 1967b; Bransford et al., 2003; National Research Council, 1996; Wong et al., 2001). Teaching for understanding places demands on teachers and learners that exceed those associated with either direct instruction or open inquiry. It “requires teachers to have comprehensive and in-depth knowledge of subject matter, competence in representation

and manipulation of this knowledge in instructional activities, and skill in managing classroom processes in a way that enables active student learning” (Cohen et al., 1993).

Until recently, there was very little known about the extent to which teaching for understanding occurs in our nation’s schools. Much of the large-scale information that exists on classroom practice comes from survey data. Although surveys have the benefit of providing information on the extent to which various strategies are being used, survey data are much weaker in describing the quality of instruction (Burstein et al., 1995; Mayer, 1999; Porter et al., 1993; Spillane and Zeuli, 1999).

A major national observation study, the Case Studies in Science Education (Stake and Easley, 1978), involving a cross-section of 11 U.S. school districts, described the conditions and needs of science, mathematics, and social studies education. The authors noted that the quality of science instruction students experienced was quite varied; while some of the observed science classes stressed important science ideas and were described as interesting to students, most “overemphasized facts and memorization” and were not seen as relevant to the students. Science education observation studies since that time have generally either been quite small, or have been conducted in the context of the evaluation of a reform initiative, in both cases limiting the generalizability of the results.

The *Inside the Classroom Study* provides new insight into the extent to which teaching for understanding is occurring in our nation’s schools. The study included observations of 180 science lessons, selected to be representative of lessons

nationally, and interviews with the teachers of those lessons. Lessons were documented and analyzed in a number of different areas, including the quality of the science content and the extent to which the classroom culture facilitated learning. The lessons were ultimately assessed on the extent to which they were likely to impact student understanding in science and develop their capacity to successfully “do” science. Findings about the national status of quality science instruction and the components of lessons that seem likely to promote student understanding have important implications for science educators.

Methodology

The study design for *Inside the Classroom* drew upon the nationally representative sample of schools that had been selected for the 2000 National Survey of Science and Mathematics Education (Weiss, et al., 2001). A subset of middle schools from the schools that participated in the 2000 National Survey were selected. To ensure that these sites would be as representative of the nation as possible, systematic sampling with implicit stratification was used. When



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a middle school agreed to participate, the elementary schools and high school(s) in the same feeder pattern were identified and one of each was randomly selected. Two science teachers were randomly selected from each school for classroom observations.

Researchers were asked to take detailed field notes during the observations, including describing what the teacher and students were doing throughout the lesson, and recording the time spent on various activities. Following the observation, the researcher interviewed the teacher about the lesson, focusing on why the particular content and instructional strategies had been selected. Researchers completed an analytic protocol using the data collected during the observation and interview, and data from the analytic protocols were weighted in order to yield unbiased estimates for all science lessons in the nation. The

weighted estimates of the frequency of classroom practices based on *Inside the Classroom* data are generally equivalent to those based on the 2000 National Survey sample, suggesting that estimates of lesson quality based on the observation data are an accurate depiction of what happens in the nation's science classes.

The Quality of Science Lessons Nationally

Inside the Classroom researchers rated the observed lessons on individual indicators in a number of areas, e.g., the quality of teacher questioning. Following the rating of individual components of the lesson, researchers were asked to provide an overall rating of the lesson. The scale observers used is divided into the following levels:

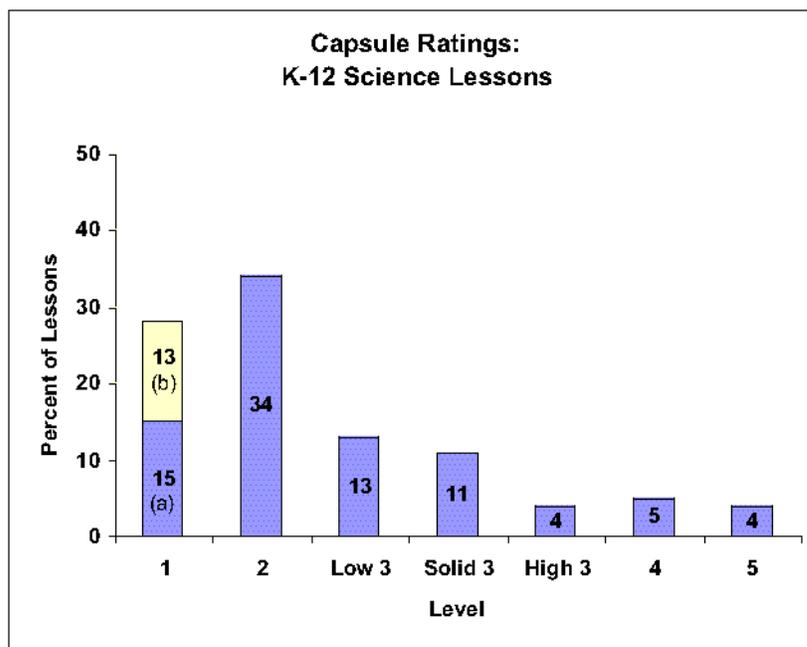
- Level 1: Ineffective instruction
 - a. passive "learning"
 - b. "activity for activity's sake"

- Level 2: Elements of effective instruction
- Level 3: Beginning stages of effective instruction (low, solid, high)
- Level 4: Accomplished, effective instruction
- Level 5: Exemplary instruction

Lessons judged to be low in quality (those rated 1a, 1b, and 2) are unlikely to enhance students' understanding of important science content or their capacity to do science successfully. While low quality lessons fell down in numerous areas, their overarching downfall tended to be the students' lack of engagement with important science. Examples of low quality lessons include:

- A primary grade lesson in which students drew their favorite animal, but never focused on science concepts;
- A lesson that attempted to teach a 3rd grade class about buoyancy, clearly not developmentally

Figure 1



appropriate for these students; and

- A class where students followed the steps through laboratory procedures, but did not seem to understand why they were doing what they were doing.

At the other end of the scale, high quality lessons (those rated high 3, 4, and 5) were designed and implemented to engage students with important science concepts; they were very likely to enhance their understanding of these concepts and to develop their ability to engage successfully in the processes of science. Regardless of the pedagogy (e.g., investigations, teacher presentations, reading, discussions with each other or the teacher), high quality lessons provided opportunities for students to interact purposefully with science content and were focused on the overall learning goals of the concept. Examples of high quality lessons include:

- A lively discussion in a science class focused on interpreting and identifying trends in data collected in lab the previous day;
- A lecture where high school students were engaged in learning about how nerve receptors are differentiated to distinguish levels of pain; and
- Students working individually on research reports related to environmental problems in their community.

In the middle, were lessons that were purposeful and included some elements of effective practice, but also had substantial weaknesses that limited the potential impact on students. The specific areas where “middle quality” lessons fell down varied. Examples include:

Effective lessons include meaningful experiences that engage students intellectually with science content.

- A small group exploration that was short-circuited by the teacher, who told the students what they should find;
- A lesson in which the needs of a subgroup of students were not addressed;
- A lesson where students were ridiculed for asking questions, which interfered with the implementation of a well-designed learning activity; and
- A discussion that involved high-quality ideas, but was too fast-paced for many of the students.

Data from the *Inside the Classroom* study indicate that most science lessons in the United States are low in quality and that there is a general lack of teaching for understanding. As can be seen in Figure 1, based on observers’ judgments, only 13 percent of K-12 science lessons in the United States would be considered high in quality, 24 percent medium in quality, and 62 percent low in quality. In the high quality lessons, students were fully and purposefully engaged in deepening their understanding of important science content. Some of these lessons were “traditional” in nature, including lectures and worksheets; others were “reform” in nature, involving students in more open inquiries. In contrast, in the low quality lessons, which included both traditional and reform-oriented lessons, learning science would have

been difficult, if not impossible.

More detailed analyses were conducted in order to learn more about the characteristics that distinguished lessons that seemed to promote student understanding from those that did not. A number of factors emerged, including the extent to which the lesson was able to:

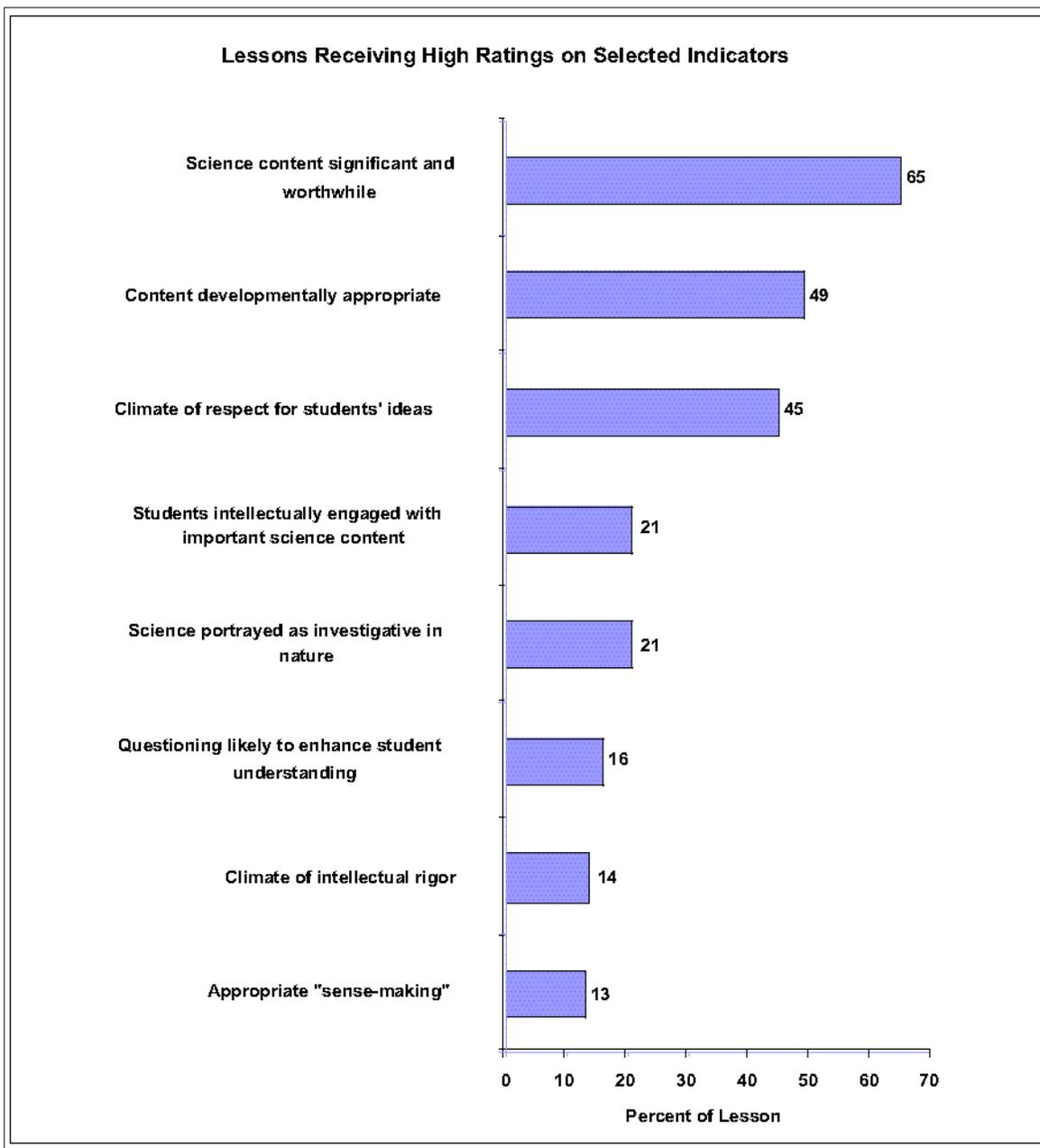
- Engage students with the science content;
- Create an environment conducive to learning;
- Ensure access for all students;
- Use questioning to monitor and promote understanding; and
- Help students make sense of the science content.

Effective Lessons Provide Students with Opportunities to Grapple with Important Science Content in Meaningful Ways

Certainly one of the most important aspects of effective science lessons is that they address content that is both significant and worthwhile. Lessons using a multitude of innovative instructional strategies would not be productive unless they were implemented in the service of teaching students important content. Based on the lessons observed in this study, science lessons in the United States are relatively strong in this area, with 65 percent of lessons judged to include significant and worthwhile content. (See Figure 2.)

It is important to note that while the majority of science lessons in the United States included important content, most lessons were nevertheless rated low. Clearly, while the inclusion of important content is necessary for high quality science instruction, it is not sufficient.

Figure 2



Effective lessons include meaningful experiences that engage students intellectually with science content. These lessons make use of various strategies to interest and engage students and to build on their previous knowledge. Effective lessons often provide multiple pathways that are likely to facilitate learning and include opportunities for sense-making.

Unfortunately, K-12 students are not often intellectually engaged with important science content, with only 21 percent of lessons rated highly in this area.

Lessons should “invite” students to purposefully engage with content

It is clear that teachers need a thorough understanding of the purpose

of the lesson in order to guide student learning. It has also been argued that *students* need to see a purpose to the instruction, not necessarily the disciplinary learning goals the teacher has in mind, but some purpose that will motivate their engagement (Kesidou and Roseman, 2002). In the ideal, lessons will “hook” students by addressing something they have wondered about, or can be induced

How science is portrayed is key to student understanding of the discipline.

to wonder about, possibly but not necessarily in a real-world context. Many observed lessons failed to incorporate strategies to gain student interest and motivation; in many cases, lessons “just started.” For example, a teacher began a 3rd grade lesson by having the students open their textbooks to the designated chapter, while she handed them a review worksheet. Similarly, a high school lesson began with the teacher distributing a packet of questions and saying, “All right now, these pages should be very easy if you’ve been paying attention in class. We talked about all of this stuff.”

Teachers who succeeded at engaging students intellectually with science content had various strategies for doing so. Some lessons that “invited the learners in” did so by engaging students in first-hand experiences with the concepts or phenomena. Others invited the students in by using real-world examples to vividly illustrate the concept. Still others used stories, fictional contexts, or games to engage students with the content of the lessons. The following are examples of lessons that were particularly successful at motivating student interest and engagement:

In a 1st grade science lesson, the teacher read a story about a girl who discovers an arrowhead in her backyard. The class then engaged in an excavation activity in pairs, where one child was the “archeologist” who found the “hidden treasures” in their

“midden [refuse heap]” and the other was a “curator” who put their “hidden treasures” in a “museum.”

* * *

In a 4th grade science lesson about the basic needs of animals and how different body parts help animals meet these needs, the teacher handed out a tail feather and a magnifying glass to each pair of students, and asked them to examine the feather, pull the barbs apart, and look for the hooks. They then pulled the feather between their fingers, making the barbs stick back together. The teacher then handed out a down feather and they repeated their investigations.

* * *

A high school physics teacher had the students explore static electricity using a Van de Graaf generator, Tesla coil, and fluorescent light tube. The teacher explained how each worked, and used students to demonstrate what happens when electrons are pulled from one source to another.

Lessons should foster students’ understanding of science as an investigative process

How science is portrayed is key to student understanding of the discipline. Lessons can engage students with concepts so they come away with the understanding that science is a dynamic body of knowledge, generated and enriched by investigation. Alternatively, lessons can portray science as a body of facts and procedures to be memorized. Based on *Inside the Classroom* observations, only 21 percent of science lessons nationally provide experiences for students that clearly depict science as investigative in nature (rated 4 or 5 on a five-point scale). The following lesson is illustrative of those that highlighted the investigative nature of science:

The focus of this 3rd grade science lesson was on the idea that Earth is a “water planet.” The teacher provided the background and motivation needed to launch the students into the

investigation through whole group discussion. Students were asked to work in groups, first to make predictions, and then to toss a “beach ball model” of the Earth and observe if their finger landed on land or water. After each group had made ten tosses, the class shared their data and compared their observations to their predictions. The lesson ended by having each group of students try to explain the data, while the recorder wrote down the group’s reasoning. The lesson was to be followed up the next day by representing the different oceans on Earth with squares on graph paper and using that to visualize how much of the Earth is made up of water, and to picture the relationships between bodies of water and land. The observer noted that the lesson was well designed, with “a focused experience using a model that should help students understand not only why the Earth is called ‘the water planet,’ but how scientists figure out the relative quantities of a substance on Earth by using scale models.”

In contrast, many lessons presented science as a static body of knowledge, focusing on compilations of factual information. The following examples are typical:

Students in a 4th grade science class were given a worksheet consisting of statements from the textbook with multiple-choice response options. The students were instructed to find the right answer and to note the page in the textbook where the answer was found. The teacher circulated among the students and helped them find the answers if they were having difficulty. The observer indicated that the questions on the worksheet were factual and low level, requiring vocabulary recognition rather than application of knowledge. A question on air pressure read: “What does a barometer measure?” The answers from which the students were asked to select included: (a) humidity, (b) temperature, (c) air pressure, (d) wind. When the groups had finished the assignment, the teacher asked them to regroup with a new partner and compare their answers and reference pages. When this assignment was completed, the teacher read the correct answers and page references from her master copy and the students corrected their worksheets. The observer noted

that the content was limited principally to definitions and terms; “although the vocabulary was important, the lesson did not encourage students to use the vocabulary as a way to communicate information and give meaning to observations.”

* * *

An 8th grade science lesson was designed to give the students a great deal of factual information on Newton’s Third Law of Motion. The students copied notes from the blackboard for half of the lesson, and the next half of the lesson was spent with the teacher asking them to recall information from the notes. The observer wrote: “The lesson was designed in a way that allowed the students to be very passive, interacting little with each other or the content. The students spent a great deal of time hurriedly copying the notes; only those students who were called on by the teacher during the review time were required to think about the content, and even that was at the basic level of recalling facts they had just written down.”

Lessons should take students from where they are and move them forward

Although it is unlikely students are learning if they are not engaged, engagement is not enough; to develop student understanding of science, lessons need to be at the appropriate level, taking into account what students already know and can do, and challenging them to learn more. Approximately half of all science lessons were rated high for the extent to which the content was appropriate for the developmental level of the students

in the class. The estimated 20 percent of lessons nationally that were judged to be at the low end of the scale on developmental appropriateness were only occasionally too difficult for the students. Sometimes students lacked the prerequisite knowledge/skills, and the content seemed inaccessible to them; at other times, the vocabulary was at far too high a level for the students. More often lessons were pitched at too low a level for some or all of the students. The following examples are typical:

Students in a 6th grade science lesson demonstrated in the introductory whole-class discussion that they already had a good grasp of what owls eat, so the subsequent activity of dissecting owl pellets to determine an owl’s diet would not advance their understanding.

* * *

Prior to the observed lesson the students had drawn the parts of the digestive system on the figure of a man, described the function of each part, and traced the path of a piece of food through the system. When they were then asked to write a story describing a cheeseburger’s journey through the digestive system, many of the students were bored with the assignment. Said the observer, “they stated this fact on numerous occasions; they passed notes; they did their hair. They were not intellectually engaged. The assignment was too obviously busy-work—they had already done essentially the same thing the previous day.”

Some lessons used multiple representations of concepts to facilitate learning, providing greater access to

students with varying experiences and prior knowledge, and to help reinforce emerging understanding. One such lesson was observed in a 7th grade science class:

Beginning with a review of the main facts about fossilization that students had been studying, the teacher provided information about how fossils can be dated and went on to explain radiocarbon dating techniques. She then led the class in constructing standard radiocarbon dating curves, which the students used to date their own “fossils” (plastic bags of pennies). The “heads” represented C-14 atoms, which the students then replaced by paper clips, representing N-14 atoms. By counting the number of C-14 atoms in their “fossil,” students were able to determine its age. Students who finished this task were then asked to create an N-14 standard curve. The observer noted that the lecture was effective, and that the use of the small group, hands-on activity “helped make this rather abstract concept more concrete and interesting.”

Effective Lessons Create an Environment Conducive to Learning

Based on the observations in this study, a classroom culture conducive to learning is one that is both rigorous and respectful. Nearly half of science lessons nationally received high ratings for having a climate of respect for students’ ideas, questions and contributions. Ratings for rigor were much lower, with only 14 percent of science lessons nationally judged to have a climate of intellectual rigor, including constructive criticism and

Table 1
Cross Tabulation of Climate of Respect and Intellectual Rigor

		Percent of Lessons		
		Intellectual Rigor, Constructive Criticism, and Challenging of Ideas Are Evident		
		Low	Medium	High
Climate of Respect for Students’ Ideas, Questions, and Contributions	Low	26	0	0
	Medium	26	1	1
	High	16	17	12

the challenging of ideas. Table 1 shows a cross tabulation of the two variables; note that only 12 percent of science lessons nationally are strong in both respect and rigor, and 26 percent are low in both areas.

Sixteen percent of science lessons were categorized as respectful but lacking in rigor. *Inside the Classroom* observers used phrases like “pleasant, but not challenging” to describe such lessons. The following examples are typical.

In a 6th grade science lesson, “the teacher appeared to want all students engaged in the lesson, and distributed her questions to various students ... [However,] intellectual rigor did not seem to be a priority, as long as students could give the verbatim responses for each cell part. Discussion of differences between plant and animal cells noted the different cell components (chloroplast, cell wall) but did not ask students to pose conjectures as to why the differences should exist, or what the effect would be, for example, if animal cells had a cell wall. The tone was friendly and supportive, but that was as far as it went.”

* * *

The observer reported that “emotionally, the culture of this 9th grade science class was good. The teacher had a warm relationship with the students, and it seemed clear that there was great deal of mutual respect. Intellectually, however, the culture in this classroom was very weak. Science was presented as facts and formulas to memorize, with no requirement that things make sense or even be internally consistent. Students were asked to respond to the teacher’s questions but did not interact with each other, or propose new ideas for the class to discuss.”

Effective Lessons Help Students Make Sense of the Science Content

Focusing on important science content; engaging students; and having an appropriate, accessible learning

The important consideration is that lessons engage students in doing the intellectual work, with the teacher helping to ensure that they are in fact making sense of the key science concepts being addressed.

environment set the stage for learning, but they do not guarantee it. It is up to the teacher to help students develop understanding of the science they are studying.

The teacher’s effectiveness in asking questions, providing explanations, and otherwise helping to push student thinking forward as the lesson unfolds often appeared to determine students’ opportunity to learn.

Researchers observed some extremely skillful questioning, where the teacher was able to use questions to assess where students were in their understanding, and to get them to think more deeply about the science content. There were many more instances where the teacher asked a series of low level questions in rapid-fire sequence, with the focus primarily on the correct answer, rather than on understanding. Questioning was among the weakest elements of science instruction, with only 16 percent of lessons nationally incorporating questioning that seemed likely to move student understanding forward. Lessons that were otherwise well-designed and well-implemented often fell down in this area.

Researchers saw teacher questioning used effectively both to find out what students already knew and to provoke deeper thinking in helping them make sense of science ideas. For example:

As the students in a 10th grade science class were examining the results of their experiment, the teacher asked questions that pushed them to examine their results further and to provide evidence for their conclusions. Examples of questions asked by the teacher are: “How could we test if there is still sugar in the reservoir?” “Why didn’t it [the iodine indicator] reach equilibrium?” and “How do you know?”

More often observers noted that the teachers moved quickly through the lessons, without checking to make sure that the students were “getting it.” As soon as the few most verbal students indicated some level of understanding, the teacher went on, leaving other students’ understanding uncertain.

By far, the most prevalent questioning pattern in science lessons was one of low-level “fill-in-the-blank” questions, asked in rapid-fire, staccato fashion, with an emphasis on getting the right answer and moving on, rather than helping the students make sense of the science concepts. The following example illustrates this pattern as it played out in one 6th grade science lesson on weather and the atmosphere:

Teacher: “The first layer is the what?”
Students: “Troposphere”
Teacher: “How many layers are there?”
Students: “Four”
Teacher: “What happens in the troposphere?”
Student: “It rains”
Teacher: “What happens in that layer?”
[Students unsure]
Teacher: “w, w, w...”
Student: “Water?”
Teacher: “What have we been studying?”
Student: “Weather.”

Teacher: "What are four forms of precipitation?"
Students: "Rain, snow, sleet, hail"

Interestingly, observers reported that some teachers asked good questions, but were so intent on getting the right answer that they supplied the answers themselves, in effect short-circuiting student thinking. Said one observer, "The teacher discouraged any comments or ideas that were not exactly what she asked for, answering her own question if the first response was not what she desired."

Teacher questioning is one way, but not the only way to help students understand the science at hand. The important consideration is that lessons engage students in doing the intellectual work, with the teacher helping to ensure that they are in fact making sense of the key science concepts being addressed. The following examples illustrate lessons that included appropriate "sense-making."

The purpose of a 5th grade science lesson was for students to know what a seed was and to understand methods of seed dispersal. The teacher started the lesson by having the students name things that seeds require in order to grow and then the whole class covered the definition of a seed. Next, the teacher elicited from students ways that seeds are carried from place to place and then the class discussed the definition of seed dispersal. The teacher then gave the class directions for the group activity. Students in groups selected an "action card" which contained a description of a method of seed dispersal. Groups then used items already available at their tables to create a model of that method of seed dispersal. The observer remarked that "the designing of models of seed dispersal provided a way for students to process their new information and to express their understanding of it in a creative and unique way." When all groups were finished creating their models, each group stood up and shared their action card and model with the entire class. The

lesson concluded with students writing in their science journals about what they had accomplished in this lesson and then each student sharing some of what they had written with the class. The observer noted, "this sharing allowed students to listen to each others' ideas which reinforced their understanding while also allowing the teacher to check for student comprehension."

* * *

Students in a high school chemistry class had been working on properties of compounds and elements. The observed lesson built upon that knowledge, focusing on compound formation. There were three main components to the lesson: (1) a quick review of the previous lesson's concepts; (2) a lecture/discussion on the new material; and (3) a question/answer review of the new material. The lesson included time for sense-making during the lecture portion of the class (the teacher asked questions throughout to ensure comprehension), and a wrap up question/answer segment at the end. The lecture itself moved through content sequentially, building from the specific to broader conclusions. Said the observer, "this was a well-designed lesson with clear objectives that were all met."

Although researchers observed some lessons where students were helped to make sense of the science content as the lesson progressed and/or at its conclusion, most lessons lacked adequate "sense-making;" only 13 percent of lessons received high ratings in this area. Many teachers seemed to assume that the students would be able on their own to distinguish the big ideas from the supporting details in their lectures, and to understand the science ideas underlying their laboratory investigations. The following lesson descriptions illustrate inadequate sense-making in science lessons.

The teacher guided a 3rd grade class through the completion of a science worksheet by referring the students to a particular question, telling them to turn to a specific page in their textbook and look for the answer,

asking one student volunteer to read the answer from the book, then writing the answer on an overhead transparency copy of their worksheet. The observer reported the following conversation as an example:

Teacher: "Let's look at lesson two. Turn to page E16. Fill in the blank. Look on the page. Matter is made of ... what?"
Student 1: "Atoms."
Teacher: "Adding heat changes a solid to a what?"
Student 2: "Liquid."
Teacher: "Good. Now read number three."

At the completion of the worksheet, the teacher then went over the questions and answers to summarize the content in the lesson. The students were instructed to keep their worksheets for the next lesson.

* * *

The observer noted that "each of the physical science topics demonstrated in this lesson was appropriate to the 9th grade curriculum (mechanical waves, sound and light waves, mixing colors), and could be grasped by these students at some level. Moreover, each of the demonstrations was in itself interesting and motivational for the students, and for the most part kept their attention. However, the teacher presented all of these demonstrations in rapid succession, without providing appropriate ties to the material studied in class. As a result, the overall effect was more show than substance. No attempt was made to anchor the demonstrations into any conceptual framework."

In summary, while the aim of instruction in all cases needs to be understanding, based on the *Inside the Classroom* observations, there appear to be multiple approaches for achieving this goal. Observers saw lessons that were well-designed and well-implemented using lectures, hands-on activities, or paper and pencil tasks to help develop student understanding of important science concepts. Observers saw other lessons using each of these strategies that seemed unlikely to lead to student conceptual understanding.

Factors that seem more instrumental than choice of instructional strategies in promoting student opportunity for learning include the extent to which lessons engage students with important science concepts; create an environment that is both respectful and rigorous; use questioning effectively; and help students make sense of the science concepts being addressed.

Discussion and Recommendations

Although people can still be heard to say “It’s okay if teachers don’t know the science, they can learn along with their students,” there appears to be a general consensus among science educators that teaching science for understanding requires teachers who themselves understand the science concepts being addressed, and who have the knowledge and skills needed to help students develop their understanding of important science concepts. Rather than focusing so much attention on which instructional strategies teachers use, student understanding would more likely be enhanced by ensuring that whatever strategies are used, instruction is purposeful, accessible, and engaging to students, with a clear and consistent focus on student learning of important science concepts.

It seems clear that teachers’ understanding of science as a discipline, and command of science disciplinary content knowledge, need to be established before they enter the K-12 science classroom. Although this is clearly a daunting task, especially when preparing elementary teachers who need in-depth background in multiple disciplines, there is simply not enough time, nor enough resources, for in-service education to compensate for major deficits in teachers’ science

Even if their initial preparation is excellent, teachers, like all professionals, need on-going opportunities for continuing education.

content background. To the extent that teachers teach as they were taught, they need to be taught for understanding if they are to teach for understanding. While some have called for the use of hands-on methodologies, cooperative learning, and other “reform-oriented” strategies in undergraduate science courses, findings from the *Inside the Classroom* study suggest that the key is not the particular strategies that are used, but rather engaging prospective teachers in ways that lead to their conceptual understanding.

It is clear that any instructional strategy can be implemented well, or implemented poorly. Open inquiries that never lead to understanding are no more helpful to learners than are uninteresting, inaccessible lectures. And lectures do not necessarily need to be boring recitations of factual information; they can be engaging explanations of phenomena. In theory, at least, a good lecture can be an inquiry experience, describing how we came to know what we know—what questions were asked; how they were investigated; which turned out to be useful pathways, and which dead ends—as well as what we don’t yet know. Enabling prospective teachers to experience a variety of well-implemented instructional strategies

in their pursuit of science content understanding, with explicit attention in their science education courses to what constitutes high quality use of each, seems most likely to prepare them to implement high quality instruction in the classrooms.

Even if their initial preparation is excellent, teachers, like all professionals, need on-going opportunities for continuing education. Professional development providers can help teachers refine their vision of effective instruction and use it to guide their lesson design and implementation. Lesson study is one potentially effective route to helping teachers understand this overall vision and improve their practice. With assistance from skilled, knowledgeable facilitators, teachers can start with group discussions of videos of other teachers’ practice, and move towards examining their own practice. In addition, with the advantage of knowing which science concepts are addressed at a particular grade level, and often which student instructional materials are being used, in-service education can be designed to provide very targeted assistance for teachers—clearly identifying the key learning goals for specific activities; sharing the research on student thinking in the specific content area; suggesting questions that teachers can use to monitor student understanding; and outlining the key points to be emphasized in helping students make sense of the science concepts. At the same time, workshops and other teacher professional development activities need to themselves reflect the elements of high quality instruction with clear, explicit learning goals; a supportive but challenging learning environment; and means to ensure that teachers are developing understanding.

In our experience, professional development often focuses on, and advocates, a particular instructional strategy, such as the use of hands-on instruction. In the lessons observed in this study, however, instructional strategy did not determine lesson quality. Consequently, we believe that professional development should focus on aspects of effective instruction that cut across instructional strategies: learning goals that are both important and developmentally appropriate; activities focused on these learning goals that capture students' interest and attention; an intellectual climate that both nurtures and challenges students; and, critically important, the need for questioning and other techniques that explicitly help students make sense of the content at hand.

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Evaluation of Systemic Reform: Learning while Doing

One state's effort to evaluate the outcomes of its systemic reform elucidated several issues critical to most large-scale efforts in education

Introduction

“The theory of systemic reform rests on some assumptions that should be examined and tested. First, systemic reform seeks greater coherence, an alignment of policies, but the education system is fragmented by design—fifty states, fifteen thousand districts, countless other agencies impacting the schools—and this fragmentation is intended to permit variation. The agencies of government responsible for the schools are divided from each other by the federal structure and by the separation of powers. They are further divided by powerful traditions of local control and parental rights. On top of that within any given jurisdiction there are a variety of stakeholders each with their own views about standards, assessment, and locus of authority” (Corcoran, 1997, p. 64).

Beginning in 1990 with the National Science Foundation's (NSF) Statewide Systemic Initiative (SSI) program, science leaders at the state, district, and local levels increasingly have faced accountability issues. Today both private and public funding agencies recommend that proposed projects

be based upon scientific research; that is, research that meets the criteria delineated in the National Research Council's book, *Scientific Research in Education* (Shavelson & Towne, 2002). Because evaluation that provides scientific-based research is the crux of the *No Child Left Behind (NCLB)* Act (Paige, Hickok, & Newman, 2000), it remains a top priority for science teachers and supervisors. This paper describes one state's efforts to evaluate its SSI, including issues that emerged during the evaluation as well

One of the goals of Ohio's SSI was to narrow any achievement gaps between identifiable subgroups of students, e.g., between boys and girls, between African American and European American students, and/or between students from different economic backgrounds.

as the lessons learned from the reform and its evaluation. Those lessons are particularly pertinent today as science teachers and district supervisors seek to meet the requirements of NCLB.

Beginning in 1994, Ohio's Statewide Systemic Initiative (*Discovery*) began to evaluate the outcomes of its reform.¹ Ohio, similar to most SSI states, focused its reform on professional development. However, it differed from others in that it offered long-term (six week), content institutes that were taught by inquiry² and provided several ways for teacher participants to receive support during the academic year (follow-up meetings, electronic networks, classroom visits from master teachers and scientists, etc.).

I'll describe the types of issues we faced as we attempted to evaluate systemic reform concurrently with doing it. The evaluation spans a period of seven years and was supported by both the SSI and a subsequent research project, funded by the NSF. Although the descriptions are specific to Ohio's reform, the issues faced as well as the lessons learned may be generalized to any large-scale reform effort.

What Issues Emerged?

Initially, we needed to know if the type of professional development we offered was indeed changing teaching practices. A series of studies,

comparing teaching practices in SSI and non-SSI classrooms indicated that teachers who had participated in the institutes and follow-up activities used inquiry methods (extended questioning, open-ended laboratories, and student-generated hypotheses) more frequently than non-SSI teachers did. As the reform progressed, we sought to find out if achievement

obtain reliable data across a variety of schools over time. We needed to assess multiple components in a complex system and to compare responses and achievement scores from cohorts of students, teachers, and principals. Therefore, a nested, three-tier design, shown in Figure 1, was used. In 1994, 150 schools were randomly selected to participate in an assessment of Ohio's SSI, and in each of the following five years over 100 participated. At these schools, designated in Figure 1 as Level A, principals and all mathematics and science teachers (for grades six through nine) completed questionnaires focusing on standards-based teaching of, parental involvement with, and administrative support for science and mathematics education.

Level B consisted of a subset of the original random sample of schools. Across the years, the number of schools agreeing to participate in Level B ranged from 12 to 16. Level B schools were selected using specific demographic factors that would enable us to assess changes in teaching and learning among Ohio's high-risk students.³ The following criteria were used to select Level B schools: they were part of the statewide random sample; they enrolled approximately 30% African American students; they had at least one teacher who had participated in the SSI's professional development programs; and they had high proportions of their students eligible for free or reduced-price lunch. At Level B schools, students completed a questionnaire that included items parallel to those on the teacher and principal questionnaires

Our first challenge was to develop a research design that allowed us to obtain reliable data across a variety of schools over time.

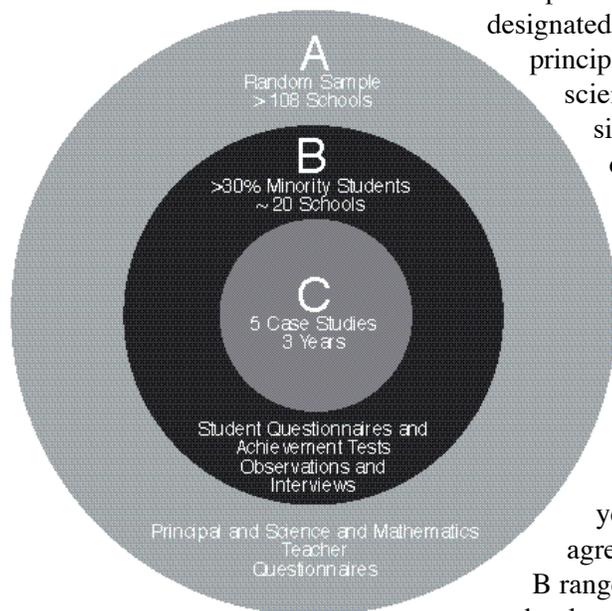
as well as a science or a mathematics achievement test that was designed to measure students' problem solving abilities and conceptual understanding. In addition, from 1994 through 1999, three or four day site visits were made to Level B schools.

Level C involved intensive, multiple year case studies of five schools, spread across Ohio and representing urban centers, small towns, urban fringe, and suburbia. At this level, extensive school and classroom observations were conducted. Students, teachers, administrators, parents, and community leaders were interviewed. Observations and interviews were made serially and contingently in the sense that decisions about whom to involve and how to involve them were dependent upon what had been learned at other levels of the study and at other schools in Level C.

We found that the nested research design produced fairly quick information at the survey (state) level to guide Ohio's continued reform, and at the school and district levels it provided ways (observation and interviews) to validate the survey data. Further, the case studies elucidated how systemic reform affected schools at different stages of readiness.

Other major issues faced were: using self-report data, blurring of the distinction between SSI and non-SSI teachers as the reform

Figure 1. Nested Research Design



differences by subgroups of students had narrowed or disappeared.

One of the goals of Ohio's SSI was to narrow any achievement gaps between identifiable subgroups of students, e.g., between boys and girls, between African American and European American students, and/or between students from different economic backgrounds. And, eventually, we sought answers as to why the reform worked in some schools and not in others and what components were replicable across sites.

Our first challenge was to develop a research design that allowed us to

progressed, comparing scores for cohorts of students across a five year time span, and collecting meaningful achievement data in an economical way. Indeed, one lesson learned is that the quality of the data must be weighed against the cost of the data.

In order to evaluate the impact of the SSI's professional development on teaching practices a set of articulated questionnaires for principals, teachers, and students were developed. At the classroom level, we hoped to diminish any self-reporting bias by having teachers and students respond to similar items. For example, as shown in Figure 2, both groups were asked to estimate the frequency that teachers used open-ended questions on a five-point Likert scale that ranged from *Very Often* to *Almost Never*. By comparing the percent of responses to the left and right of the center (zero) bar, one can see how well student responses supported those of their teachers.

Inquiry Tests were developed by two task forces composed of university mathematics or science faculty, members of Ohio's SSI academic leadership teams, and other Ohio teachers. Each task force

identified eighth grade public release items from the National Assessment of Educational Progress' (NAEP) 1990 and 1992 tests. Items were selected specifically to measure



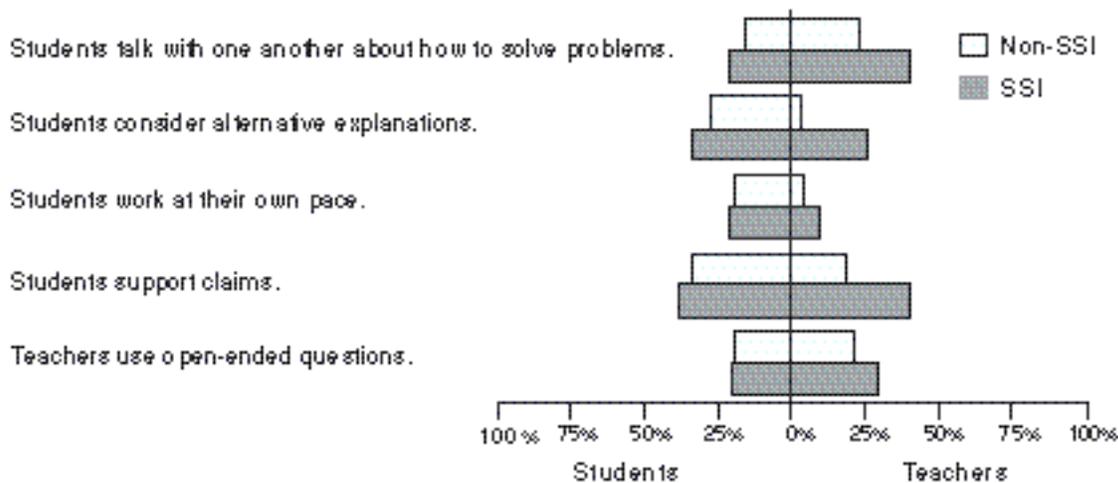
One of the most perplexing issues faced in the evaluation of systemic reform was the gradual loss of any control group.

student ability in problem solving and conceptual understanding. Beginning in 1995, students of SSI and non-SSI "match" teachers took the tests.⁴ Although the SSI focused on grades six through nine, only seventh and eighth graders were tested because of the age appropriateness of the test. Using the Cronbach Alpha Test of Internal Consistency, reliabilities were established at .86 in mathematics and .94 in science. Achievement data collected in 1995 served as base-line

data, and all test scores in subsequent years were calibrated on the 1995 scale.

A basic methodological issue faced by all long-term reforms is valid comparisons across different student cohorts in different educational settings. Item Response Theory (IRT) was used to address that issue. For example, IRT was used to refine and revise the achievement tests. Because cohorts of students were assessed, it was important to develop a bank of items, called anchor items, that were common across the years. These items, which anchored the test from year to year, were continually monitored in three ways: (1) evaluation of misfit statistics, (2) analysis of differential item functioning (DIF), and (3) consideration of external issues that might cause items to drift. Items showing any of those characteristics were removed as anchor items. Anchor items allowed us to compare responses on questionnaires and student test scores across the years, although the questionnaires and tests were modified as the reform progressed in order to retain sensitivity to its changing nature (e.g., implementation of the

Figure 2. Students and teachers responding "Very Often" to use effective classroom practices in mathematics and science



The quality of data had to be carefully weighed against the cost of obtaining the data.

Ohio Proficiency Test in science, wider use of standards-based teaching, wider dissemination of the state model curriculum, better alignment of state and district policies). (For a detailed description of instrument development and revision, please see Scantlebury, Boone, Kahle, & Fraser, 2001.)

Although carefully designed paper and pencil achievement tests provided a very useful measure of student learning, we were sensitive to the limitations of using only one measure. In 1998, we explored the use of performance assessments by implementing performance tasks from the Third International Mathematics and Science Study (TIMSS) in selected schools. In addition, multiple-choice versions of selected TIMSS' tasks were added to the Inquiry Test in science. Analysis of the data suggested that paper and pencil tasks alone inadequately measured student learning, particularly for urban, African American students (Harmon, 1991; Kelly, 2001). However, expense as well as difficulties in both delivery and scoring caused us to drop performance testing from the evaluation.

One of the most perplexing issues faced in the evaluation of systemic reform was the gradual loss of any control group. If a reform is systemic (and working), participants infect their colleagues with their enthusiasm and ideas. Our review of approximately 90 teacher portfolios as well as our monitoring of the SSI's electronic "teacher

lounge" suggested wide sharing of inquiry-based lessons, alternative assessments, and other teaching materials. Because there was clear blurring of the two groups (SSI and non-SSI teachers) in some schools, we moved to comparisons that involved the percent of SSI teachers in a school.

Ohio's systemic initiative was based on equity, and our evaluation focused on equity issues, particularly at Level C. We used the *Equity Metric* (Kahle, 1998) as one way to interpret findings both within one site and across sites. It proved to be an effective model for analyzing why the reform works in some schools or districts and not in others (Hewson, Kahle, Scantlebury, & Davies, 2001). Further, it helped to elucidate what aspects of the systemic reforms could be replicated across sites (Kahle and Kelly, 2001).

We were sensitive to the issue of causality, because we could not directly relate outcomes to treatment (the SSI's professional development

institutes and follow-up activities). As a consequence, we used multiple sources of data and looked for similar trends. Although attribution could not be established, common trends suggested more than a chance phenomenon.

What Did We Learn?

The underlying assumption ... is that systemic reform is a proven strategy and that we know how to do it, and therefore the only important question is "are they doing it right?" (Corcoran, 1997).

As the above quote suggests, when NSF initiated the SSI program, systemic reform was not a proven strategy for improving science and mathematics education. Therefore, questions concerning efficacy, efficiency, and effectiveness needed to be addressed by evaluations. Yet, those evaluations faced many unresolved issues in research and design as well

Figure 3. Comparison of seventh and eighth grade mathematics scores of students taught by SSI teachers

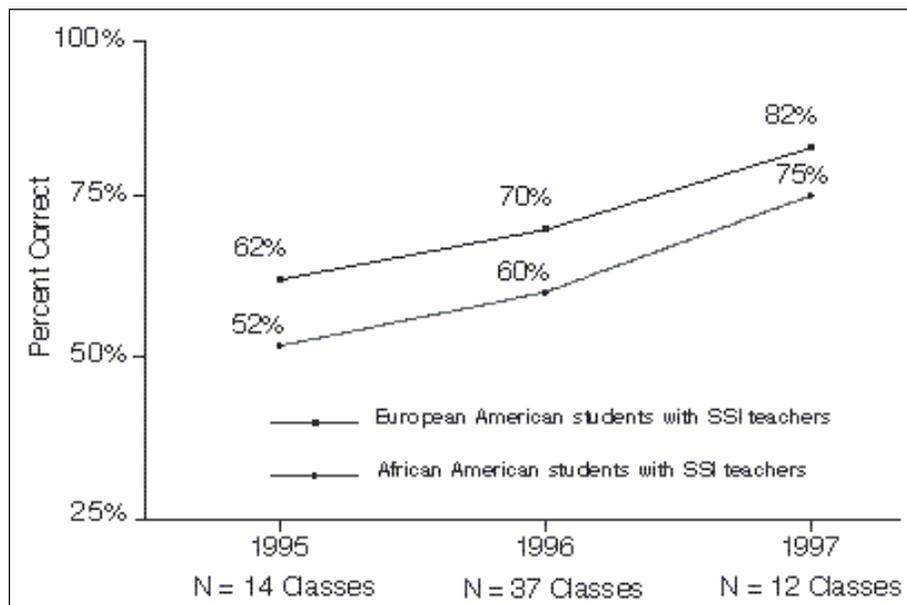
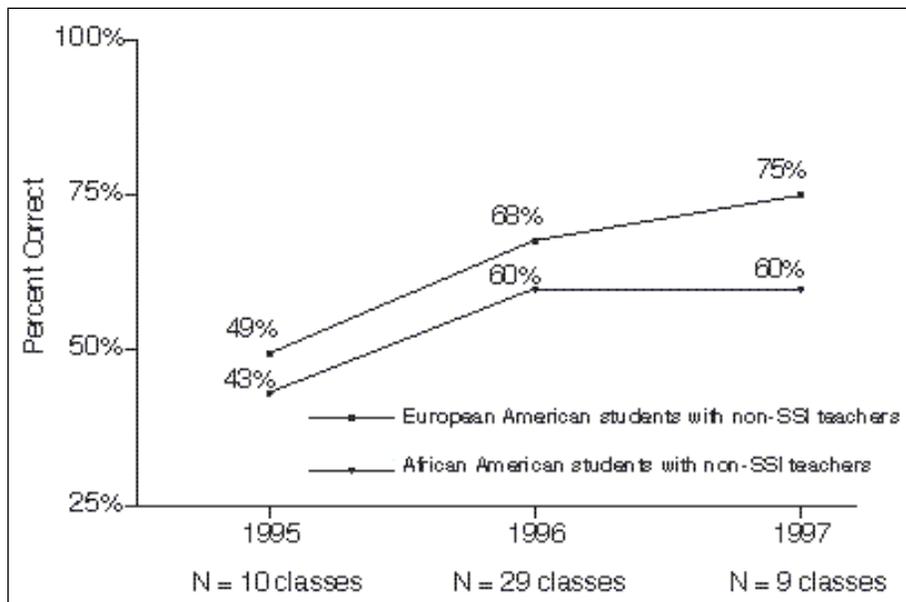


Figure 4. Comparison of seventh and eighth grade mathematics scores of students taught by non-SSI teachers



as in analyses and interpretation. For example, simply obtaining reliable and valid data across a state, particularly in Ohio's largest urban districts, was complex. The quality of data had to be carefully weighed against the cost of obtaining the data. Therefore, data on teaching practices, student attitudes, and principal support of science and mathematics education were collected by questionnaires. However, those data were confirmed by visits to Level B schools. In addition, because data collected with questionnaires are subject to self-report bias, principals, teachers, and students responded to similar items. Responses of different groups to the same items could be compared, increasing confidence in the findings.

To address the issue of causality, we analyzed achievement data in multiple ways. In one analysis, data were examined by student racial group; two independent studies looked at gender differences, while a third analysis assessed possible bias related

To address the issue of causality, we analyzed achievement data in multiple ways.

to teacher characteristics. First, a comparison of 610 science students in matched science classes indicated that both African American girls and boys in classes taught by SSI teachers scored 9% higher on the science test than did their peers in matched classes. In addition, European American girls in SSI classes scored 10% higher and European American boys scored 5% higher than their peers in non-SSI classes (Damnjanovic, 1998). Achievement also was analyzed at the class level using only classes that had at least 25% of their students in a minority group (either 25% African American or 25% European American students). Although many classes did not fit that

profile, we had a representative sample (comparable numbers of classes taught by SSI and non-SSI teachers) for three years in mathematics. One hundred and eight classes, enrolling over 3000 students, in ten schools were involved. As Figure 3 shows, the achievement gap in mathematics in classes taught by SSI teachers narrowed from 10.4 percentage points in 1995 to 7.5 in 1997. On the other hand, according to Figure 4, it widened from 7.3 percentage points in 1995 to 15.1 in 1997 in classes whose teachers had not participated in the SSI's professional development.

In addition, two independent analyses established that gender gaps in both mathematics and science decreased both across and within racial groups (Damnjanovic, 1998; Goodell, 1998). Another analysis compared the predicted scores of students whose teachers had completed the SSI professional development to those of students whose teachers had applied to participate but had not yet done so. That is, all teachers were volunteers.⁵ The positive effect of the SSI's professional development was suggested by higher scores (from 2% to 7%) on both the mathematics and science tests of students (N = 2374) whose teachers had completed SSI's sustained professional development, compared to those who had not (Supovitz, 1996). Because all teachers were volunteers, this analysis controlled for the "volunteer" effect.

Other analyses examined the impact of the number of SSI teachers in a school or district. In 1998 and 1999, we were able to obtain Ohio Proficiency Test (OPT) mean scores in science and mathematics for eighth grade students in several large urban districts. Schools were clustered, depending upon the percentage

of SSI teachers in their faculty. In total, nearly 12,000 students were involved. The percent of minority students in the schools ranged from 77 to 79%, while between 67 and 71%

Clearly, the percent of teachers involved in the professional development was a factor in students passing the science proficiency test.

passing the science proficiency test. One explanation is that students in schools with *High* percentages of SSI teachers were more likely than students in *Medium* or *Low* participating schools to have had several SSI teachers. That explanation was verified by the class and school visitations that occurred at Levels B and C.

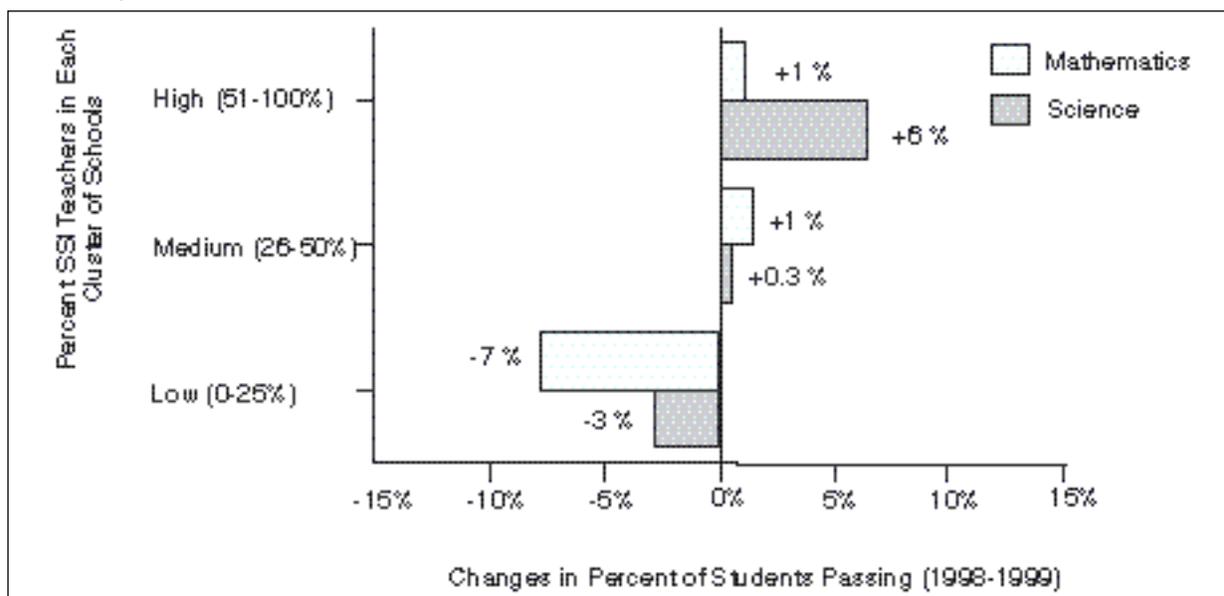
Another set of analyses involved Hierarchical Linear Modeling (HLM) procedures; they were used to more closely examine teacher influences on students' achievement and attitudes in science. HLM is a relatively new statistical technique that can examine variables measured at different levels (individual, teacher, and school), as

Because of the SSI's focus on teacher professional development and equity, our analyses were directed toward explaining variations in African-American students' achievement and attitude scores in relation to teacher differences. We found that approximately 16% of the variance in achievement scores on the Inquiry Test in science and 10% of the variation in attitude scores on the student questionnaire could be attributed to between-teacher differences (Kahle, Meece, & Scantlebury, 2000).

What Lessons Were Learned?

Our efforts to evaluate the outcomes

Figure 5. Changes in percent of urban students passing the Ohio Proficiency Tests in mathematics and science by percent of SSI teachers in school



of students in the schools qualified for free or reduced-price lunch. As shown in Figure 5, if over 51% of the teachers in a school had participated in the SSI's professional development activities, it was designated as *High* participation. Clearly, the percent of teachers involved in the professional development was a factor in students

well as variables measured on different scales (e.g., categorical and continuous variables). It is considered the most appropriate procedure for dealing with hierarchical data structures in which individuals are nested within other organizational contexts, such as instructional groups, classrooms, or schools (Bryk & Raudenbush, 1992).

of one state's systemic reform elucidated several issues critical to most large-scale efforts in education. Our success (or failure) in addressing those issues produced lessons learned that are applicable to similar efforts. The first lesson learned was that a nested, multi-layer research design enabled us to collect appropriate data at several

levels (student, teacher, classroom, and school). Further, it allowed us to balance relatively inexpensive data collection techniques (survey) with intensive (and expensive) ones like the case studies.

The initial lesson learned was that the evaluation design had to address all parts of the system and that it needed to include various types of research techniques.

How to responsibly address causality also was an important lesson learned. Because multiple factors and at least ten years are involved in any systemic reform, it is impossible to attribute change to any one factor or condition. To address the thorny issue of causality, especially in reporting student achievement data, we performed multiple analyses, using different controls and techniques, and we looked for patterns of change. A third lesson learned was the value of statistical techniques (IRT) that allowed us to conduct the evaluation across many years and in many sites using cohorts of students, rather than a longitudinal sample. We experimented with performance items only to find that the value added was not equal to the costs incurred—a fourth lesson learned. And, the fifth lesson was the value of interpreting quantitative data through the lens of qualitative data. That lesson is particularly pertinent today when one considers reports emanating from the quantitative data required by the NCLB legislation. Recently we learned that only 52 schools in the country have been identified as dangerous. Los Angeles, Chicago, Miami, Detroit, Cleveland, San Diego, Baltimore, and Washington, D.C. have no violent schools; and New York City only has two (Schouten & Toppo, 2003). Clearly, the criteria used to identify a

The initial lesson learned was that the evaluation design had to address all parts of the system and that it needed to include various types of research techniques.

dangerous school varied in 52 different state surveys, and in no state were the quantitative findings verified by qualitative observations.

Due to the evaluation's findings of positive outcomes, the Ohio reform of science and mathematics education has been maintained with state funding. The reform continues to face new situations and issues due to changing conditions in the state (the Ninth Grade Ohio Proficiency Tests are being replaced by Tenth Grade Ohio Graduation Tests, and new science and mathematics standards have been adopted). However, both the issues faced and the lessons learned continue to inform the reform as well as its evaluation.

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Endnotes

1. A member of the first cohort of SSI states, all of Ohio's eligible cities (Columbus, Cleveland, and Cincinnati) received USI awards, and five Ohio counties were part of the Appalachian RSI.
2. The initial institutes were based on the University of Washington's *Physics by Inquiry* curriculum (McDermott, Shaffer & Rosenquist, 1996). Later, content-based, inquiry courses were developed in mathematics and life science.
3. Ohio's public school population is a little more than 1.8 million, with African Americans constituting its largest racial/ethnic group (17%). Over a half million students are eligible to receive free or reduced-price lunch.

4. A "Match" teacher taught similar classes as an SSI teacher in the same school; that is, ninth grade, general biology teachers who had and who had not participated in the SSI's professional development would be "matched," by experience, gender (if possible), and type of license.
5. Evaluations of the systemic initiatives have debated the "volunteer effect;" that is, the difficulty of reaching beyond the teachers who volunteer for professional development. The concern is that "volunteer" teachers, as a group, may differ substantively from the "non-volunteer" teacher group.

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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.

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,

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

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

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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.

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

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

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).

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

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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.

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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Preservice Science Teachers' Concerns Through Classroom Observations and Student Teaching: Special Focus on Inquiry Teaching

This study develops a picture of how preservice science teachers' instructional concerns changed during a yearlong science methods program spanning classroom observations through student teaching

Introduction

The ability of teachers to assess and change their pedagogy through reflection is viewed as an important part of teacher professional development (National Research Council (NRC), 1996). Preservice teachers' reflections on their practicum experience through journals, case studies, or seminar discussions have become a vital part of teacher training (Schön, 1987; Zeichner & Liston, 1987). Van Manen (1977) described three stages of reflection: technical rationality, practical action, and critical reflection (Ferguson, 1989). Many preservice and novice teachers' initial reflections fail to advance beyond Van Manen's first stage if the teacher is not given additional support from experienced educators (Ferguson, 1989; Yost, Sentner, & Forlenza-Bailey, 2000). At this first stage, teachers are primarily concerned with the procedures and technical knowledge needed to run a classroom. At the second stage, teachers' reflections are concerned with not only technical procedures, but also the consequences and quality

of those actions. At Van Manen's highest level, teachers reflect on the ethical and political meaning of their knowledge and actions (p. 227). High quality reflection is essential for the professional growth and development of educators (NRC, 1996). In addition to improving preservice teacher performance through self-assessment, reflections can be a medium through which student teachers' beliefs and concerns are made visible.

Much research has focused on analyzing and understanding the attitudes and beliefs of beginning teachers (Kagan, 1992). Preservice teachers' preexisting beliefs act as "filters" to help them understand their education course content and their experience as student teachers (Hollingsworth, 1989).

Apprentice teachers often enter education programs with overly idealistic, optimistic, and affective attitudes of teaching and pupil behavior based on their own experiences as students (Weinstein, 1989). Some researchers believe that these images of teaching and teachers,

developed from years of schooling, are difficult to change even with extensive educational courses and teaching experience (Pajares, 1992). Beliefs also influence student teacher progression from novice to expert teacher (Berliner, 1986).

Fuller (1969) identified three progressive stages in beginning teacher development. Preservice teachers begin in the stage of "no concern", in which they have only vague ideas about teaching, and their ideas stem from their own experiences as students themselves (p.218). Student teachers then reach the stage of "concern with self", in which they are concerned with issues of their own adequacy as a teacher in dealing with class control and the ability to teach the subject matter (p.211). Finally, towards the end of student teaching, the preservice teachers reach the "concern with pupils" stage in which they are concerned with pupil learning and progress (p.211). Fuller (1969) and Kagan (1992) believed that beginning teachers must develop routine and systematic

management and instructional skills before they can focus on pupil learning. In contrast, Veenman (1984) in a review of 83 beginning teacher studies found that students may deal with all three levels at the same time and, therefore; do not require the successful attainment of each level in sequence. Additionally, preservice teachers have been portrayed as being capable of dealing with subject matter content and pupil learning early in their development (De Jong, 2000; Feiman-Nemser & Parker, 1990).

Apprentice teachers often enter education programs with overly idealistic, optimistic, and affective attitudes of teaching and pupil behavior based on their own experiences as students.

Preservice teachers' views of important teaching skills are also outlined in the literature. Veenman (1984) found that classroom discipline was perceived as the primary problem among beginning teachers, followed by the ability to motivate students, and assess individual differences (p.154). Others have found that novice teachers focus more on general teaching skills than student learning (Kagan & Tippins, 1992; McDermott, Gormley, Rothenberg, & Hammer, 1995). Wilson and Cameron (1996) analyzed the journals of 28 preservice teachers during their first, second,

and third year of student teaching. The dominant emphasis of student teacher journals, regardless of year, was on "instructional skills", with first year student teachers focusing on teacher actions and third year teachers discussing instruction in more complex and holistic ways (p.183). Wilson and Cameron's research findings follow Fuller's (1969) teacher stages with first year teachers being concerned with self and third year teachers progressing to concern of pupils.

In addition to general pedagogical concerns, preservice teachers should be concerned with specific pedagogical content knowledge that will lead to student comprehension (Shulman, 1987). Inquiry teaching has been stressed in the *National Science Education Standards*, (NSES), as well as many state science standards as a way to improve science process skills and pupil understanding (NRC, 1996). The NSES define inquiry as an activity that involves questioning, examining resources, gathering and analyzing data, developing explanations, and communicating results (p.23). Preservice teacher concepts of inquiry teaching are important if, as suggested in the literature, preexisting beliefs shape the way that these teachers will conduct their classrooms in the future (Hollingworth, 1989). Researchers also question the ability of novice teachers to perform inquiry methods with little classroom experience and numerous misconceptions (Crawford, 1999; Hayes, 2002). Preservice teachers often fear the loss of teacher control associated with inquiry and have difficulties translating content into authentic student tasks (Crawford, 1999; Hayes, 2002). Beginning teachers often incorrectly perceive inquiry teaching as chaotic, difficult, and equivalent to hands-on activities

(Eick & Reed, 2002; Rankin, 2000). If inquiry-based instruction is to be incorporated into science classrooms, preservice teachers must not only view it as a vital part of science teaching, but also have practical experience with the method in the classroom.

The purpose of this study was to develop a picture of how preservice science teachers' instructional concerns changed during a yearlong science methods program spanning initial classroom observations through student teaching. As described above, inquiry teaching methods are stressed in the NSES and other reform documents, but are not yet implemented in many secondary teachers' classrooms. For this reason and because inquiry teaching methods were stressed during the preservice teachers' science method courses, another goal of this study was to determine the teachers' ideas about inquiry teaching and the influence of their methods course and classroom experience on their use of inquiry teaching methods during their student teaching.

Methods

Participants

Thirteen secondary preservice teachers (PT), (six male, seven female), who were enrolled in a yearlong science methods program at a large midwestern university, participated in this study. Nine PTs were graduate students with undergraduate degrees in science or engineering. The remaining four PTs were undergraduates majoring in education with a concentration in science. Twelve (92%) of the students had limited previous teaching experience. Five of the graduate students and one undergraduate had experience teaching classes at the

university level, six students taught short summer science programs or summer camps, and one student had no previous teaching experience.

University Courses

The students' university science education program consisted of a 6-week methods course (2.5 hours per week) and 30 hours of classroom observation during the fall semester. General topics covered in the discussion based fall semester course were inquiry science, questioning techniques, evolution, writing performance objectives, and the national and state science standards. In the spring semester, the PTs participated in a second more intensive 6-week methods course (17.5 hours each week), 50 hours of classroom observation, and 10 weeks of student teaching. PTs also met with their professor at six 2-hour seminars during their 10 weeks of student teaching. The spring semester course focused on teaching methods (inquiry, demonstrations, case history, concept mapping, questioning), lesson planning, state standards, and preparation of a teaching portfolio. The PTs had the same experienced professor during both courses.

Data Collection

The researcher was a non-participant observer in both semester methods courses and the six student teaching seminars. The researcher wrote field notes during these course observations, focusing on the PTs' concerns and the content of the courses. In addition to these class observations, the PTs were given an open-ended pre-observation questionnaire during the second week of the fall semester methods course and an open-ended post-observation questionnaire after completion of

Preservice teachers often fear the loss of teacher control associated with inquiry and have difficulties translating content into authentic student tasks.

their 30 classroom observation hours, at the end of the fall semester. The pre-observation questionnaire, in addition to demographic questions, asked the PTs whether they thought inquiry was a good method for teaching science content. The post-observation questionnaire asked the PTs whether they observed inquiry science teaching during their classroom observations, and asked them to describe their cooperating teacher's most typical instructional methods.

During each of the PTs' two classroom observation periods (fall and spring), they were required to write six modified KWL (What I know, What I want to know, What I Learned, and What I would do differently) reflections, each 250-400 words in length (Ogle, 1986). The reflections were to cover planning, instructional delivery, or assessment and were part of their science methods course requirements. The PTs chose how many reflections they wrote on each topic. The reflections were generally one-half to one page in length, with one paragraph written on each part of the KWL format. The student teachers were also required to write 10-15 modified KWL reflections during their student teaching.

After student teaching in the spring semester, an open ended questionnaire was administered to the PTs during their final student teaching seminar. This questionnaire asked the PTs to describe their cooperating teacher's three main instructional methodologies, to describe their relationship with their cooperating teacher, and to describe any inquiry lessons they taught during their student teaching. The questionnaire also asked the PTs to describe any constraints they had to using inquiry teaching methods during their student teaching.

Data Analysis

All student questionnaires and reflections were analyzed using content analysis (Merriam, 1998). Using this method, the researcher searched through the data for recurring themes or events that could be used as categories to further reduce the findings and represent the documents' contents. The researcher then attempted to account for the diversity in the data with the developed categories. New categories were developed or old categories reformulated until all the data were described with the developed categories. The number of PT's statements that fit into each category were counted and recorded to provide an overall picture of these teachers' concerns throughout the study period.

Categories were validated through triangulation with survey responses, reflections, and observations of PTs during their student teaching seminars (Merriam, 1998). A second researcher also studying this group of PTs read and separately coded a portion of their reflections. The trustworthiness of the data was further strengthened with the discussion and eventual agreement

of the two researchers' findings with respect to the PTs' concerns (Denzin & Lincoln, 1998).

Results

Pre/Post Observation Inquiry Questionnaire

In the pre-observation questionnaire, all of the PTs recorded that the inquiry methodology was a good way to teach science content. The PTs explained that this method helped to increase student critical thinking, motivation, ownership of concepts, and science comprehension. However, eight PTs (62%) reported that inquiry was not always the best way to teach science content. These PTs argued for a mixed teaching methodology that would reach all students' learning styles. Others stated that the inquiry method was too lengthy to use all the time and still cover the necessary science content. One PT stated that content needed to be introduced before inquiry lessons in order to allow students to grasp the "big picture". Another PT thought that inquiry science was only for students that were "good at linking scientific concepts".

Only three out of the 13 PTs (23%) observed an inquiry-type lesson during their classroom observation hours. These consisted of a lesson on growing mustard seeds in different soils, testing enzyme action, and testing solubility of substances. All three lessons were guided inquiry that required the students to make predictions and design their own scientific procedures after being given the initial question to answer (NRC, 2000).

The PTs' descriptions of a typical lesson taught by their cooperating teacher were combined with the

methods discussed in the KWL reflections to give a better picture of the methodologies observed during classroom observations and student teaching. The cooperating teachers taught using a variety of methodologies with an emphasis on small group activities (n=10), laboratories (n=10), and lectures (n=8). Several PT's also described their cooperating teacher's typical lessons as including questioning techniques (n=6), student worksheets (n=6), and science demonstrations (n=4). The pre-service teachers observed little if any inquiry lessons.

Student Teaching-Inquiry

Similar to classroom observations, only four out of the 13 PTs (31%) observed their cooperating teacher using an inquiry-type lesson during their pre-student teaching observations during the spring semester. However, all of these "inquiry" lessons were described as either inquiry demonstrations with questions or teacher lectures with student questions and not student hands-on inquiry investigations. During the spring methods course, PTs were taught inquiry demonstrations, in which students make predictions and answer questions to determine the outcome of a demonstration. PTs observed no open or guided inquiry laboratories during their student teaching. One preservice teacher commented that their cooperating teacher did not think that inquiry worked. The most commonly observed lessons consisted of lectures, laboratories, and worksheets.

Despite the PTs' limited experience with inquiry in the classroom, 85% (n=11) of the PTs reported teaching at least one inquiry lesson during their

student teaching. Four PTs reported teaching at least two inquiry-type lessons. Through an interpretive process, preservice teacher comments were categorized into seven major categories: instructional delivery, assessment, planning, classroom management, student issues, cooperative/supervising teacher issues, and personal issues. Of the two PTs who did not teach inquiry lessons, one stated that "my students could not handle it" and the other gave time limitations as the reason for not including this methodology. One PT who tried inquiry said, "I tried to use inquiry in an adaptation activity, but the students were very unwilling to think and come up with new thoughts." Table 1 summarizes the most common concerns of teachers in five of the seven categories.

Reflections

A total of 286 preservice teacher KWL reflections were analyzed and divided into three time periods: observation-1 reflections (n=69) during the fall semester, observation-2 reflections (n=61) at the beginning of spring semester, and student teaching reflections (n=156) during the spring semester. Through an interpretive process, preservice teacher comments were categorized into six major categories: instructional delivery, assessment, planning, student issues, cooperative/supervising teacher issues, and personal issues. Although all coding categories were developed from interpreting the reflections, the methods' course instructor gave three of these categories (instructional delivery, assessment and planning) to the PTs as general topics of focus for the reflections. Table 1 summarizes the most common concerns of the teachers in five of the six categories.

Table 1. Preservice Teacher Concerns in Five Major Areas

Number of Preservice Teachers			
Instructional Concerns	Observation 1	Observation 2	Student Teaching
Instructional Methods	13	13	13
Teacher behavior to ensure student understanding	9	10	11
Improve/change instruction	8	11	10
Relate content to student interests	4	5	7
Prior Knowledge	4	4	7
Comparison to own school experience	3	3	7
Interactive Learning	2	6	9
Instructional Pace	2	5	4
Assessment Concerns			
Grading/test construction	9	7	12
Difficulty level and amount	8	6	6
Motivational tool	6	1	3
Use variety	6	3	4
Student cheating	4	3	8
Low/high test grades	1	1	10
Fair to students	1	2	2
Planning Concerns			
Equipment/Materials	6	6	7
Preparation Time	5	9	12
Time management	4	6	12
State Science Standards	3	1	1
Special planning	2	3	5
Flexibility	1	0	9
Classroom Management Concerns			
On/off task student behavior	11	6	12
Methods to reduce student problems	5	3	5
Control	3	1	5
Discipline to students	3	–	4
Organization	3	5	7
Management style	3	2	4
Student Concerns			
Engagement	11	11	11
Differences	7	5	9
Affective	6	7	12
Understanding	6	5	13
Effort	2	1	11
Weak skills (math, reading)	2	3	5

Instructional Delivery

PTs' instructional delivery concerns were divided into 16 categories during observation-1, 18 during observation-2, and 21 during student teaching. PT comments on instructional delivery focused most prominently on types of instructional methods, changes the preservice teachers would make to instructional delivery after viewing a lesson, and techniques to increase student understanding of content (Table 1). Many PTs, in their observation reflections, expressed a desire to change or improve their cooperating teacher's instruction by adding more interactive lessons, student questions, and demonstrations. During student teaching, the PTs reacted to their own failed instruction with similar suggested improvements. They suggested changing teacher communication techniques, adding concrete examples, increasing content depth, and adding interactive student-centered activities.

During all reflection periods, teacher behavior to ensure student understanding included such items as adding formative assessments, improving explanations, and breaking down concepts into smaller more understandable chunks. The PTs were also concerned with relating content to student interests and making sure that the students' prior knowledge about a concept was understood and incorporated into instructional delivery.

Assessment

Preservice teachers' assessment concerns were divided into 11 categories during all three reflection periods. PTs reflected on methods of assessment, grading, and test construction issues most during all three reflection periods. However,

during student teaching, more PTs focused on student test grades than the level of assessment or amount of assessment, which was the third most reflected category during both observations. At least three PTs discussed the importance of using multiple assessment methods during each reflection period, with a focus on using writing assignments or student presentations.

Planning

PTs' planning concerns were divided into 10 categories during observation-1, 6 during observation-2, and 7 during student teaching. Preservice teachers concerns with planning varied little over the observation and student teaching periods. During all reflection periods, preservice teachers were concerned with lesson planning, time management, preparation time, and material/equipment ordering. Planning flexibility and planning for special classroom circumstances (e.g., substitutes, half-days, snow days) became a heightened concern of teachers during their student teaching. Snow days were occasions in which the school day was delayed for several hours in the morning due to severe weather conditions. Planning lessons and curriculum to include the state science standards was a concern of at least one teacher during each reflection period.

Classroom management

Although not initially asked to write reflections on classroom management, all of the PTs discussed concerns over this topic during their student teaching. PTs' classroom management concerns were divided into 9 categories during observation-1, 5 during observation-2, and 10 during student teaching. One preservice teacher did not

Ideally, competent cooperating teachers should provide useful feedback, share resources, and provide freedom for preservice teachers to try new ideas and methods.

discuss classroom management during observation-1 and four did not during observation-2. All other preservice teachers' concerns dealing with classroom management are summarized in Table 1. Most classroom management concerns dealt with on/off task student behavior (mostly off task), student discipline, teacher control issues (rules), classroom organization (absences, late work), and methods to reduce student problems. During observation-1, five preservice teachers commented on their cooperating teacher's lack of classroom management skills or control. During student teaching, preservice teachers' instruction often suffered from their inadequate classroom management. One preservice teacher stated, "I was definitely concentrating on discipline issues instead of content issues", and another said that "the activity didn't go as smoothly because of my lack of complete control".

Student Issues

PTs' student concerns were divided into seven categories during observation-1, six during observation-2, and seven during student teaching. Preservice teachers' concerns with students focused on student engagement in lessons, student effort

(or lack of), student differences (learning styles, learning abilities), student understanding of content, and affective comments. Affective student comments dealt with students' attitudes toward a lesson, and teacher-student relationships. Examples of PTs' affective comments include statements such as "students and I need to be more comfortable with each other" or "students really enjoyed this lesson". The number of teachers concerned with student issues increased for all categories during their student teaching, except student engagement, which remained unchanged. Concerns with student understanding progressed from superficial comments such as, "students were confused" or "students seemed to grasp the concepts" during observation-1 to more evaluative comments during their student teaching. For example, one PT stated, "I had them talk me through a couple of examples so I could see if they really had an understanding".

Cooperative/Supervising Teachers

PTs' cooperating teacher concerns were divided into five categories during observation-1 and observation-2, and eight during student teaching. PTs' comments about their cooperating classroom teachers focused on their agreement or disagreement with teaching methods, the guidance and support given to them, and their control over lessons during their teaching. PTs more often disagreed with their cooperating teacher's instructional methods. PTs wanted to see more inquiry-based instruction, labs, and hands-on student activities. For example, one preservice teacher said that his cooperating teacher believes that "science laboratories are activities, and not much time should be spent on them". Three students commented on

either a lack of freedom or lack of help from their cooperating teachers during their student teaching. However, not all comments were negative; one preservice teacher stated that her "cooperating teacher continues to be a joy to watch". Two PTs failed to comment on their cooperating teachers during observation-1 and observation-2 and one during student teaching.

Personal Issues

PTs' comments about their teaching confidence, frustrations, and enjoyment with teaching were categorized as personal issues. Only three PTs' reflections dealt with personal issues during observation-1. All three of these teachers commented on their lack of confidence in teaching. Ten PTs commented on self-confidence issues during observation-2, with eight negative comments and two positive comments. The remaining three PTs did not reflect on personal issues during observation-2. All thirteen PTs reflected on personal issues during their student teaching. Twelve of the PTs' concerns dealt with self-confidence (4 positive, 4 negative, 4 both), six with being overworked/tired, four with frustration over lack of student effort or classroom management, and six with positive comments about teaching. One PT stated, "It is amazing to watch great teachers do what they love-it is an art". Other teachers commented on their enjoyment when interacting with students, planning particular lessons, and seeing students achieve at high levels.

Conclusion

The preservice teachers' reflections emphasized self-concerns over pupil concerns as predicted by Fuller (1969). Self-concerns, which focused on instructional delivery, assessment,

and planning, changed little over the reflection periods. Overall, the student teachers' reflections focused on procedural and classroom management concerns as predicted in the literature (Veenman, 1984). Despite the focus on self-teaching issues, the preservice teachers were able to reflect on issues of pupil learning throughout the reflection periods. Preservice teachers' concerns with student issues such as student content comprehension and student differences in learning did increase from their classroom observations to their student teaching. The complexity of these concerns also increased during their student teaching. These findings argue against a strict stepwise development of teachers (Fuller, 1969; Kagan, 1992), in favor of a more complex model of development that allows for interaction between teacher pedagogy concerns and pupil learning (Grossman, 1992).

As suggested above, the student teachers most often reflected at Van Manen's (1977) technical level, with concerns about how to apply their pedagogical knowledge. However, preservice teachers' comments on how they would adapt instructional and assessment methods to increase student understanding show their concern with the consequences of their actions on student learning. These reflective statements, which fit better into Van Manen's second level, were prevalent during all three reflection periods and varied in depth from student to student. One student reached Van Manen's critical reflection level, questioning the value of extrinsic motivators and the structure of modern school systems. This student also experienced the most "cognitive dissonance" realizing during student teaching that a science teaching career

was not his passion (Hollingsworth, 1989).

Ideally, competent cooperating teachers should provide useful feedback, share resources, and provide freedom for preservice teachers to try new ideas and methods (Connor & Kilmer, 2001). Research also shows that cooperating teachers have a direct impact on their student teacher's behavior and attitude (Yamashita, 1991). In this study, preservice teachers often disagreed with their cooperating teachers' advice or teaching style. Disagreements between cooperating teacher methods and preservice teacher methods may be helpful in providing the "disequilibrium" needed to push forward science teaching reform (Hollingsworth, 1989; Piaget, 1978). The preservice teachers reflected on a need for students to "think" more and become more actively involved in the classroom. However, without adequate support, preservice teachers may revert back to the way that they were taught instead of trying to incorporate new teaching techniques if they are uncomfortable or uncertain about their abilities (Grossman, Wilson, & Shulman, 1989). One student with two cooperating teachers reported that "my teachers said I could do whatever I wanted [during my student teaching], but were not able to guide me in using anything other than lectures, demonstrations, and homework review." These three methods were the ones the cooperating teachers were reported using most often in their classrooms.

Teacher education students who experience lower levels of support from cooperating teachers often

... without adequate support, preservice teachers may revert back to the way that they were taught instead of trying to incorporate new teaching techniques if they are uncomfortable or uncertain about their abilities.

have elevated stress and reduced teaching performance during student teaching (Murray-Harvey *et al.*, 2000). Preservice and cooperative teachers need to develop collaborative relationships that will benefit both parties and lead to increased student performance.

Although few preservice teachers observed inquiry lessons during their observations and student teaching, 85% of the teachers experimented with teaching inquiry. However, many of the preservice teachers' definition of inquiry differed from the definition found in the *National Science Education Standards* (NRC, 1996). Keys and Bryan (2001) discuss similar confusion among novice teachers when teaching inquiry-like lessons. Whereas questioning should be seen as the beginning phase of an inquiry investigation (NRC, 2000), some preservice teachers in this study

believed that questioning or predicting was the complete inquiry process. The preservice teachers in this study also encountered frustration and difficulties with teaching inquiry in the form of negative student attitudes, time restraints, and lack of student effort. Teacher beliefs that constrain quality inquiry teaching are prevalent among both inservice and preservice teachers (Crawford, 1999; Keys & Kennedy, 1999). Lack of experience with inquiry based instruction in the science classrooms, places greater emphasis on university instruction to teach preservice teachers this science pedagogy. The lack of experience also increases the chances that confusion and frustration will overcome the process.

The teachers' reflections demonstrate their knowledge of the skills needed to be competent teachers (Reynolds, 1992). The preservice teachers were able to reflect on the importance of developing lessons that take into account student interests and prior knowledge. The teachers were also concerned with engaging students in active substantive lessons and developing strategies to increase student understanding. Despite these strengths, the reflections also illustrate the preservice teachers' weaknesses. These areas can be used to focus instruction at the university level in an attempt to develop teachers with a solid teaching base. This study also shows a need for further experience and instruction on inquiry-based learning and a need for a greater change in preservice teacher focus from self-concerns to pupil learning concerns.

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Moral and Ethical Dimensions of Socioscientific Decision-Making as Integral Components of Scientific Literacy

An argument is made that socioscientific decision-making occupies a seminal place in scientific literacy and attention to morality and ethics must be included in the science curriculum.

Science educators have appropriated many meanings for the phrase “scientific literacy” (Champagne & Lovitts, 1989). This paper advances an argument that in order to maintain the usefulness of such a malleable phrase, its users must explicitly address the context of its use. Based on the vision of science education articulated in standards documents from the United States (American Association for the Advancement of Science, 1990); (National Research Council, 1996) and abroad (Council of Ministers of Education Canada Pan-Canadian Science Project, 1997; Millar & Osborne, 1998; Queensland School Curriculum Council, 2001), this paper advances a conception of scientific literacy which involves the negotiation of socioscientific issues. In other words, becoming scientifically literate requires, at least in part, the ability to make informed decisions regarding socioscientific issues. Central to socioscientific issues are moral and ethical implications; therefore, the promotion of scientific literacy requires curricular attention to the moral and ethical implications

of socioscientific issues. This paper reviews how the Science-Technology-Society movement has addressed socioscientific decision-making and outlines an alternative approach that more explicitly focuses on the moral and ethical implications of socioscientific issues.

Scientific Literacy Ambiguity

In the current era of standards and reform, the phrase “scientific literacy” has garnered a great deal of attention from the science education community. Despite the reform movement’s emphasis on scientific literacy, the architects of modern science education

In the current era of standards and reform, the phrase “scientific literacy” has garnered a great deal of attention from the science education community.

reform did not coin the phrase; in fact, it has appeared in the literature for almost fifty years. Paul Hurd is credited with first publishing the phrase in 1958, but the notion that underlies scientific literacy for all citizens can be traced back to at least the beginning of the century (Laugksch, 2000). Despite (or maybe because of) the fact that scientific literacy has been a part of the landscape of science education for a considerable length of time, its meaning remains mired in debate.

In today’s educational environment, “scientific literacy” has become the descriptor of science education’s ultimate aims. In many ways, it has become the criterion for assessing curriculum and pedagogy; new approaches are evaluated by the extent to which they promote scientific literacy. Consequently, researchers and practitioners have a tendency to conceptualize the construct in manners that support their own goals for education. In other words, educators substantiate their research and teaching agendas by linking them to the promotion of science literacy, which is frequently defined by their agendas

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(Champagne & Lovitts, 1989; De-Boer, 2000; Laugksch, 2000). This tautology leaves the field with many distinct perceptions of what scientific literacy entails. Most science educators would agree that promoting scientific literacy is *a* (if not *the*) primary goal of science education, but no such consensus exists regarding the meaning of scientific literacy itself. The multiple definitions of scientific literacy tend to focus on three main areas: processes, knowledge, and attitudes (Jenkins, 1990). Attempts to operationalize scientific literacy typically appeal to at least one of these areas, and the arguments usually proceed along the following lines: “The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe” (Rubba & Andersen, 1978, p. 450). This particular example highlights the knowledge dimension, but equally viable statements are made regarding the processes of science as well as attitudes towards science. Additionally, some delineations of scientific literacy combine multiple goals as in the case of equating the

concept with building “scientific habits of mind” which involves processes, epistemic considerations, and attitudes (Zeidler & Keefer, 2003).

Responding to this apparent incongruity, some authors claim that scientific literacy is an ill-defined concept of little practical utility (Champagne & Lovitts, 1989; Laugksch, 2000). The fact that educators appropriate multiple meanings to the phrase supports the contention that scientific literacy is an ill-defined concept; however, this non-specificity does not necessarily condemn the concept. Scientific literacy can still be useful in describing the aims of science education so long as appropriate qualifiers and support are supplied. When appealing to scientific literacy, authors need to explicitly address their ideas regarding the concept and provide a rationale for their given perspectives. In the tradition of qualitative research (Lincoln & Guba, 1985), providing such a description shifts the assessment of applicability from the investigators or authors to the audience. Because scientific literacy can mean different things to different people, authors must qualify their use of the phrase so that their readers can choose to accept or reject the stated position.

Operationalizing Scientific Literacy

The standards documents provided by the American Association for the Advancement of Science (AAAS; 1990; 1993) and the National Research Council (NRC; 1996) as well as perceived needs of current elementary and secondary science students, provide the framework from which scientific literacy will be framed for this report. *Science for All Americans*, a seminal reform document, defines

scientific literacy as a multifaceted construct including the following elements:

being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes. (AAAS, 1990, pp. xvii-xviii)

The *National Science Education Standards* define a scientifically literate person as someone who is able to “use appropriate scientific processes and principles in making personal decisions” and “engage intelligently in public discourse and debate about matters of scientific and technological concern” (NRC, 1996, p. 13). Both of these conceptualizations characterize scientific literacy as an active objective; they provide benchmarks for using scientific knowledge and processes. A logical question to ask in response to this analysis is use of knowledge and processes towards what end? In answering this question, it is important to remember the documents’ intended foci. We need look no further than the title of one, *Science for All Americans* (AAAS, 1990), and the opening sentence of the other, “scientific literacy has become a necessity for everyone” (NRC, 1996, p. 1). Scientific literacy is not a goal

restricted to the academically elite or those who show the promise of becoming tomorrow's scientists, doctors, and engineers; scientific literacy is for every student. If this is the case, then scientific literacy cannot involve the level of technical sophistication required by particle physicists, molecular biologists, and chemical engineers. Most students will not become professional scientists and engineers and, therefore, will not need to master the specifics of the de Broglie hypothesis, posttranslational protein regulation, or any number of other science discipline-specific information. In fact, most professional scientists probably do not even understand intra-discipline complexities beyond their own specialties (Pool, 1991); it seems outlandish to expect student scientific literacy to eclipse that of practicing scientists.

What then do all students actually need to be able to do in order to achieve scientific literacy? They need to be able to use scientific processes and habits of mind to solve problems faced in everyday life and to confront issues that involve science and make informed decisions (Driver, Newton, & Osborne, 2000; Kolstø, 2001; Patronis, Potari, & Spiliotopoulou, 1999). Science pervades nearly all aspects of modern society and in order to ensure the proper functioning of such a society within the context of democracy, its citizens must be capable of considering and resolving scientific issues. In support of this contention, consider the science-related issues of crucial import as evidenced by their prominence in political campaigns, media reports, and personal decisions. A small sample of these issues includes cloning, stem cell research, alternative fuels, global warming, ozone depletion, nuclear energy, and genetically

modified foods. Because the class of scientific issues that requires public input (as opposed to other scientific issues most frequently addressed by professional scientists) necessarily involves societal factors, these issues have been termed socioscientific issues (Kolstø, 2001; Zeidler, Walker, Ackett, & Simmons, 2002). Therefore, at least one component of scientific literacy must be the ability to negotiate socioscientific issues and produce informed decisions.

Most science educators would agree that promoting scientific literacy is a (if not *the*) primary goal of science education, but no such consensus exists regarding the meaning of scientific literacy itself.

Socioscientific Decision-Making

Socioscientific decision-making requires, at minimum, three interrelated aptitudes. 1) In order to negotiate and make decisions about socioscientific issues, individuals must possess requisite knowledge about the science underlying the issues or the skills needed to acquire that knowledge. This cannot be viewed as a prescribed list of facts because the issues themselves are constantly evolving and no static body of knowledge can fully prepare a decision-maker. The ability to find information and process new data is essential for handling new issues as

they emerge in the context of real life (Bingle & Gaskell, 1994; Kolstø, 2001). 2) Socially and politically active participants in a society dependent on science and technology must also have an understanding of the nature of science (NOS). NOS components such as the efficacy of data and its analysis, the evolutionary and revolutionary nature of scientific epistemology, and the social embeddedness of scientific progress contribute to the status of scientific claims. In order to apply scientific knowledge, particularly to cases of social import, decision-makers need an understanding of the nature of scientific knowledge (Kolstø, 2001; Sadler, Chambers, & Zeidler, in press; Zeidler et al., 2002). 3) Finally, individuals making socioscientific decisions must have an appreciation for the moral and ethical dimensions associated with these issues. Despite the objectivity that positivist science attempts to portray, socioscientific issues involve moral and ethical dilemmas that lack an objective "Truth." Decision-makers cannot compartmentalize science and ethics and still deliver an informed decision; ethics and morality are inseparable from science in the context of socioscientific issues. Therefore, if scientific literacy incorporates socioscientific issues, programs that promote scientific literacy must explicitly attend to moral and ethical components (Bingle & Gaskell, 1994; Kolstø, 2001; Zeidler, 1984; Zeidler et al., 2002). The inability to successfully utilize any of these three aptitudes will significantly hamper one's ability to make judgments regarding socioscientific issues and by extension will limit scientific literacy.

Of the three aptitudes described, scientific knowledge acquisition, NOS understanding, and awareness

of moral and ethical issues, the final is the most contentious suggestion for inclusion in science curricula. Arguing for science students to learn science content is not a difficult case to make. Understanding information from the domain of science is intuitively synonymous with science education. Likewise, the call for embedding NOS in science curricula is not particularly revolutionary. While debate exists over what exactly constitutes NOS and how these themes should be taught, ample support has been levied in favor of making NOS a significant component of modern science education (Abd-El-Khalick, Bell, & Lederman, 1998; McComas, Clough, & Almazroa, 2000). In contrast, strategies for dealing with ethical dilemmas are typically not associated with the canon of elementary or secondary school science. However, research in the area of socioscientific decision-making has produced mounting evidence that morality and ethics are central to the processes in which individuals engage when considering and resolving these issues.

Moral and Ethical Aspects of Socioscientific Issues

This section will review studies, in science education, which provide evidence that morality and ethics contribute significantly to socioscientific decision-making. Zeidler and Schafer (1984) analyzed college student ideas regarding an environmental dilemma. Trends emerged from the group discussions indicating that the participants incorporated morality in their decision-making. Several student groups concentrated on whether the actions proposed justified the end results. Other students displayed decision-making patterns whereby they integrated

Decision-makers cannot compartmentalize science and ethics and still deliver an informed decision; ethics and morality are inseparable from science in the context of socioscientific issues.

personal experiences, affect, and moral reasoning. Fleming (1986a; 1986b) also investigated influences on socioscientific decision-making. He interviewed adolescents as they considered nuclear power and genetic engineering. Fleming concluded that most students (70%) employed moral reasoning in the resolution of the issues posed. The propensity for individuals to rely on moral factors for socioscientific decision-making was also confirmed in Bell and Lederman's (2003) work with college professors. Each of the 18 participants responded to four socioscientific issues (fetal tissue implantation; the relationship between diet, exercise, and cancer; global warming; and the link between cigarette smoking and cancer). Eighty-five percent of the responses involved moral, ethical, or value considerations. Global warming was the only issue in which some participants failed to cite morals, ethics, or values. Pedretti (1999) conducted an intervention study with a combined class of fifth and sixth grade students as they studied a unit related to mining. In pre-intervention interviews, 22% of the students alluded to moral considerations such as assessing whether the options were

“good” or “bad,” but they offered little elaboration. Following the intervention, over half of the students talked about “good,” “better,” and “right” decisions and justified the use of these terms in a moral context. Transcript excerpts provided in the article revealed that students actively contrasted the notion of rights vs. societal laws, made utilitarian calculations of effects, and applied principles of justice. Pedretti (1999) also suggested that most students adopted one of two environmental ethical perspectives: homocentrism or biocentrism. Sadler and Zeidler (2004) chronicled the tendency for college students to construe genetic engineering issues as moral problems. These authors concluded that the participants employed the following morality frameworks as they considered negotiated gene therapy and cloning dilemmas: consequentialism, deontology, moral affect and moral intuitionism. In a follow-up study using similar kinds of genetic engineering prompts, Sadler (2003) substantiated the influence of both moral emotions and intuitions as seminal components of socioscientific decision-making.

Philosophers, ethicists, and science educators have argued that socioscientific issues naturally involve the moral domain (Andre, 2002; Carse, 1996; Zeidler et al., 2002), but whether actual decision-makers rely on moral principles and/or emotions in the negotiation of socioscientific issues is an empirical question. Taken together, the studies just reviewed present compelling evidence to support the contention that decision-makers do, in fact, employ morality and ethics as they work to resolve socioscientific issues. The result is consistent across a variety of age levels spanning middle

school (Pedretti, 1999), high school (Fleming, 1986a), college (Sadler & Zeidler, in press; Zeidler & Schafer, 1984), and adult professionals (Bell & Lederman, 2003). In addition, these studies confirm the significance of morality in a variety of socioscientific decision-making contexts including environmental issues (Pedretti, 1999; Zeidler & Schafer, 1984), genetic engineering (Fleming, 1986a; Sadler & Zeidler, 2004), nuclear power (Fleming, 1986a), and health issues (Bell & Lederman, 2003). It should be noted that these findings do not suggest that decision-making of individuals are naturally moral in a normative sense. They confirm that decisions naturally involve moral considerations from a meta-ethical perspective. The section which follows will explore the extent to which science curricula has/has not reflected this conclusion.

STS: Intent and Limitations

The most significant and sustained curricular movement with ties to socioscientific issues is the science, technology, and society (STS) movement. This educational approach has attempted to bring scientific issues with social influences and ramifications into elementary and secondary classrooms. It was initiated as a means to accomplish goals of science education reform and is consistent with the promotion of scientific literacy as a chief goal in science education (Solomon & Aikenhead, 1994; Yager, 1996). STS education involves learning experiences in which students explore the relationships between science, technology, and society by focusing on real-life issues that involve these domains. Beyond this broad description, the particulars of STS education vary significantly among the curricula and instruction

classified as such. Approaches under the STS heading may be as discrepant as a discrete course devoted to a particular topic, a methodological style of instruction in a specific science discipline, and an ancillary text box discussing the relationship between science and technology in a socially pertinent issue in the midst of a science textbook (Pedretti & Hodson, 1995). Despite the vast range of the STS movement and its admirable intentions, the movement has fallen short of developing the socioscientific decision-making aspects of scientific literacy. In the previous section, three aptitudes were presented as requisite components for socioscientific decision-making: content knowledge or acquisition, NOS understanding, and appreciation for the moral and ethical components. The STS approach attempts to address knowledge acquisition and to a lesser extent, NOS understanding, but explicit attention to moral and ethical components of socioscientific issues is not present in most (if any) STS curricula.

Positive reports on the efficacy of STS approaches populate the research literature landscape in science education for outcomes such as conceptual understanding of content material (Aikenhead, 1994; Tsai, 2000; Yager & Tamir, 1993), interest in learning about science (Aikenhead, 1994; Solbes & Vilches, 1997; Yager & Tamir, 1993), and appreciation for the interconnections between science, technology and society (Aikenhead, 1994; Rye & Rubba, 2000; Solbes & Vilches, 1997). However, the literature is devoid of any reports verifying improved decision-making with respect to the ethical implications of socioscientific issues as a result of STS education. This missing, but important link stems from a lack of

attention directed towards the morality and ethics associated with these decisions. Support for this contention can be found in analyses of literature pertaining to the STS movement as



The materials used in the preparation of teachers typically do not address the morality and ethics of socioscientific decision-making.

well as examples from content-based textbooks and secondary science methods books.

In a recently published anthology of STS research, Miller (2000) provides a description of what it means to be scientifically literate from an STS perspective. He suggests that scientific literacy is an understanding of basic science vocabulary and an appreciation for the nature of scientific inquiry.

Individuals who demonstrate a high level of understanding on both dimensions are the most capable of acquiring and comprehending information about a science or technology policy controversy, and these individuals will be referred to as being “well informed” or “scientifically literate.” (p. 29)

From this perspective, the mastery of science vocabulary and methods equips an individual to make responsible decisions about socioscientific issues. Distinct in its absence is any reference to the ethical dimensions inherent to “science or technology policy

controversies.” Another author from the same volume echoes these sentiments in levying criticism against science textbook treatment of STS issues. DeBettencourt (2000) cites problems with explanations, term confusion, and inadequate data among other concerns, but she never refers to the dearth of information regarding the ethical implications of the issues in question.

A critic could argue that the absence of moral and ethical dimensions of STS issues in research literature could just result from a bias in publication; perhaps researchers are just not interested in writing on the subject, but it actually is present in curricula. Unfortunately, this does not seem to be the case. Many commonly used secondary science textbooks do contain STS components, but they typically provide nothing more than widely interspersed boxes of text, disarticulated from other material, that highlights the interconnectedness of science, technology, and society (for examples see (Campbell, Mitchell, & Reece, 1997; Johnson, 1998; LeMay, Beall, Bobblee, & Brower, 1996; Martini, 1998; McLaughlin, 1999; Miller & Levine, 1998a; Sager, Ramsey, Phillips, & Watenpaugh, 1998; Spaulding & Namowitz, 1997; Tocci & Viehland, 1996). It is true that science textbooks are not the most important factor in determining classroom instruction; teachers should occupy that role, but there is little evidence to suggest that teachers are given the tools to go beyond STS approaches offered in texts. The materials used in the preparation of teachers typically do not address the morality and ethics of socioscientific decision-making. Current, popular secondary science education methods textbooks tend to discuss STS

approaches either as stand-alone chapters or subsections related to instructional options, but they do little more than draw connections between the related domains and suggest increased student interest in this class of issues (for examples see Chiappetta & Koballa, 2002; Trowbridge, Bybee, & Powell, 2000).

This report is not meant to condemn the STS movement because as stated previously, the movement has produced positive outcomes in some areas; nor is this report attempting a thorough review of all STS curricula or research because such an undertaking would fill volumes. Its intent is not even to suggest that no STS instruction has ever accomplished the promotion of the socioscientific decision-making aspects of scientific literacy. However, it does aim to support the claim that the

To move forward in this area, science supervisors, department heads, teachers, curriculum designers, and the individuals who support them including university level science educators need to facilitate the inclusion of socioscientific issues in science classrooms with explicit attention paid to their ethical implications.

STS movement, in general, has fallen short of highlighting the moral and ethical dimensions of socioscientific issues, which necessarily restricts the curricula’s ability to foster socioscientific decision-making. In discussing the rhetoric that characterizes the implementation of STS curriculum versus the results of its application, Pedretti and Hodson (1995) capture the movement’s shortcomings.

We want to enable students to move from the capacity to talk knowledgeably about environmental and health issues and other matters with a scientific and technological dimension, toward engagement in personal action for effecting change—a much more radical view of STS education than is commonly the case. (p. 464)

Adopting a more radical view of STS so that students are empowered to engage in personal action is synonymous with the socioscientific decision-making aspects of scientific literacy advanced earlier in this paper. In order to move students beyond the capacity to talk about issues and identify the interconnectivity between science and society, as the more radical view suggests, the science education community needs to address the real-life ramifications of these issues including the moral and ethical dimensions.

Implications

This paper has attempted to lay out a rationale for 1) offering the promotion of scientific literacy as a fundamental goal of science education, 2) including socioscientific issues as a significant component of scientific literacy, and 3) asserting that moral

and ethical considerations are central to socioscientific decision-making. In addition it reviewed the science, technology, and society movement in order to gain perspective on how socioscientific issues have been treated in science curricula. Although STS approaches have successfully raised awareness of the importance socioscientific issues, they generally have not advanced the ethical dimensions of these issues. To move forward in this area, science supervisors, department heads, teachers, curriculum designers, and the individuals who support them including university level science educators need to facilitate the inclusion of socioscientific issues in science classrooms with explicit attention paid to their ethical implications. This recommendation should not be interpreted as a proposal requiring science teachers to become ethicists. It is, however, suggesting that promoting the ability to make informed decisions regarding scientific issues that students will inevitably confront in their everyday lives should be central to their experiences in science classrooms. Because morality and ethics are natural aspects of the process of negotiating socioscientific issues, they must be included in any educational program aimed at promoting responsible decision-making.

This conclusion still leaves the role of the teacher as an open question. While a background in ethics or moral philosophy might be helpful for teachers who wish to adopt the proposed approach, it is not necessary. What is necessary is the creation of classroom environments in which the expression of ideas, including those associated with personal value systems, is encouraged. This is a

Because morality and ethics are natural aspects of the process of negotiating socioscientific issues, they must be included in any educational program aimed at promoting responsible decision-making.

goal that teachers can achieve by fostering a tolerant community in their classrooms where students are able to voice dissenting opinions and explore their belief systems. In addition, students need to feel that their science experiences can encompass more than traditional images of objective data. Incorporating curricular activities such as role-plays and debates is one approach to achieving these goals (Simonneaux, 2001), and a variety of examples already exist (Brown & Dias, 2003; Cannon, Chun, & Kitchens, 2000; McLaughlin & Glasson, 2003; Racich, 2002; Sadler & Zeidler, in press; Sadler & Zeidler, 2003; Webster, 2002). Writing assignments designed to encourage student exploration of their own thinking regarding controversial socioscientific issues as well as the perspectives held by others provide other additional activities.

As an example of what this approach might look like, consider the issue of genetically modified foods (GMF). International scientific, business, agricultural, and political communities are currently embroiled in debate over the status and accepted uses of animal and plant crops which have been

genetically altered (Charles, 2001; Nottingham, 1998; Pence, 2002). This issue could naturally be positioned within a biology course. The issue could serve as a vehicle for introducing concepts related to heritability as well as the specifics of molecular genetic processes. Instruction might also focus on the mutual interactions of science and society. But the learning experiences should not be concluded by visiting only these content and NOS goals. If the true aim of this instruction is to help students build decision-making skills, teachers have a duty to broaden the discussion. Moral and ethical dimensions are central to the debate surrounding GMF, and learning experiences that do not address these dimensions present students with a partial view of reality and fetter their ability to make informed decisions. Ethical ramifications associated with producing, marketing, and consuming genetically modified foods as well as the policies which regulate these practices are as important to decision-making as genetics concepts. To focus attention on the morality and ethics inherent to GMF issues, teachers could encourage student to grapple with some of the following questions. Should organisms be unnaturally altered by gene replacements or additions? Will genetically modified crops impact natural populations of organisms? Can individuals and/or corporations patent genes? Do farmers have the right to raise crops of their choice? Can genetically modified foods reduce worldwide hunger? Do consumers have a right to know if products have been genetically altered? Should manufacturers be forced to divulge information that will adversely affect their business? Confronting students with these open-ended problems provides them with an

initiation into the moral complexity of GMF. Teachers may choose to delve further by challenging students to explore the responses of various perspectives to these ethical quandaries and encouraging students to use these experiences to help build their own positions and rationales. In taking this type of approach, teachers need not provide students with prescribed solutions to any of the ethical questions just listed and therefore, do not require expertise in ethics and moral philosophy. Rather, teachers need to help students recognize the moral and ethical dimensions of socioscientific issues and encourage students to reflect critically on their own ideas as well as those of their classmates and potential stakeholders.

Critics might argue that genetically modified foods represent one of many socioscientific issues and may not be representative of others in terms of its ethical dimensions. While it is true that individual issues may vary in the extent to which ethics and morality impact decision-making, it seems likely that most possess at least some ethical dimensions. This trend will only increase as molecular genetics and other biotechnologies flourish, alternative fuel searches continue, and environmental concerns increase.

Conclusion

The following excerpt is taken from the preface of a recently published book on moral education:

[The authors] believe that moral and civic messages are unavoidable in higher education and that it is better to pay explicit attention to the content of these messages and how they are conveyed than to leave students' moral and civic socialization to

chance. (Colby, Ehrlich, Beaumont, & Stephens, 2003)

By substituting a few phrases, this statement reflects the central argument of this paper. Ethics and morality are unavoidable in the contemplation of socioscientific issues and it is better to pay explicit attention to these aspects than to leave a major facet of socioscientific decision-making to chance. Rather than overlooking or actively ignoring the ethical implications of socioscientific issues, educators have a responsibility to address them. If the promotion of scientific literacy is an important aim of science education, and socioscientific decision-making occupies a seminal place in scientific literacy, then attention to morality and ethics must be included in science curricula.

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Recipients' Views of the Role of Christa McAuliffe Fellowships in Science Education¹

Results are presented that identify the dimensions of the perceptions of Christa McAuliffe Fellows regarding the impact of their participation on their classroom teaching and the relationship of these dimensions to selected demographic variables.

The world continues to be reshaped by change and technology. Space exploration is central to these changes by providing unlimited opportunities for expanding mankind's understanding of the universe through scientific research. One such far-reaching opportunity lies in education's role in the space program. The importance of education in America's space program was clearly defined in 1965 by NASA's first administrator, James E. Webb: "NASA's educational programs and services are generally aimed at college or university levels, but also include space-science material, for elementary and secondary schools to assist in updating classroom instruction and student participation." (Levy, 1965). NASA's Space Education Centers provide motivational materials that are an asset to any teacher's curriculum. Classroom teacher Christa McAuliffe was no exception. She took advantage of these space-science materials as well as her own ideas as a master teacher. She was a visionary teacher who had the capacity to reach out into the future and inspire her students to

think critically about the world around them: the world in which they would live and work in the near future.

In addition to being a master teacher, she also wanted to be the first

... the use of space to motivate science education is at an all-time high.

teacher to travel and teach in space. In July 1985, NASA selected Christa McAuliffe to become the first teacher in space (Wilford, 1986). Her dream and mission was intended to reawaken the pioneer spirit in Americans, especially students and teachers, and to demonstrate to the world that the space program was accessible to everyone (Richman, 1986). In effect, this mission was to open space flight to the public and humanize the experience. Unfortunately, this dream never became a reality for

Christa because the mission failed. On January 28, 1986, the world watched the Challenger launch at 11:38.03 a.m. with excitement, admiration, and high expectations. However, within two minutes, America's first classroom teacher in space vanished when the Challenger exploded at 11:39.14 a.m. Although Americans were stunned and mourned the loss of Christa McAuliffe and the other six astronauts, America's space program was destined for even bolder ventures. Out of Challenger's ashes, grief, and remorse came a renewed entrepreneurial determination to move full speed ahead and to not disappoint the seven men and women who gave their lives daring to break the bonds of Earth (Reagan, 1986). As a national recognition to America's first teacher in space, the *U.S. Congress enacted the Christa McAuliffe Fellowship Program* in 1986 (Public Law 99-498, 1986). This Program awards a one-year sabbatical to one classroom teacher in each of the 50 states and U.S. territories for study, research, or academic improvement. Upon completion of the

¹Note. A preliminary version of this paper was presented at the 49th International Astronautical Congress, Melbourne, Australia.

Fellowship, the teacher is required to return to the classroom for two years to share the Fellowship experience with other teachers, students, and the educational community at large. It is interesting that NASA announced that the Teacher in Space Program would be resumed (NASA, 2002) less than two months prior to the space shuttle Columbia disintegrating upon re-entry, again postponing a teacher going into space. However, the use of space to motivate science education is at an all-time high.

Need to Teach Critical Thinking Skills

The chief executive officer of Xerox Corporation reported that only a small percentage of young Americans sampled in the “National Assessment of Educational Progress” could reason effectively about what they read and write (Applebee, 1987). These data are alarming because they suggest that the majority of our youth do not have the critical thinking skills needed in an economy that is now based on information and knowledge. Today the office, not the factory, is the center of working Americans. In order to provide a critically thinking workforce that has the ability to interpret, infer, evaluate arguments, recognize assumptions, and understand deduction, it is essential that educators consistently explore and search for ways to teach critical thinking skills at every level.

While most educators agree there is a need to teach students how to engage in critical thinking, the lack of consensus as to what is meant by critical thinking has led to inadequate teaching of these skills. This inadequacy can be divided into two categories: what thinking skills we choose to teach and how we choose to teach them. Controversy exists as

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to which thinking skills to teach, and educators either do not understand or cannot precisely define these skills. With regard to the implementation of these skills, many educators fail to provide the instruction that promotes critical thinking; focus on too many skills without giving the students adequate time to master these skills; and utilize achievement tests that may inhibit the development of critical thinking skills (Beyer, 1984). Nothing is more important in the education of our students than for educators to help students to think critically about their world (Hugenberg, 1995).

As early as 1923, Jean Piaget challenged teachers to reevaluate their goals for students and to promote critical thinking rather than conformity. Piaget described two important educational goals. The first “principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done—men who are creative, inventive, and discoverers. The second goal of education is to form minds which can be critical, can verify, and not accept everything they are offered.”

(Ginsburg, 1969). As we move toward a global and information technology-based society, it is important that our students understand international and cultural diversity and become sensitive to different points of view. The key to this understanding and increased sensitivity is critical thinking: identifying and challenging assumptions and exploring and imagining alternatives (Brookfield, 1987). In essence, critical thinking means a student takes a holistic approach to solving a problem and assuring all dimensions of the problem have been examined. Based on these issues, the purpose of this study was to identify the perceptions of classroom teachers awarded the Christa McAuliffe Fellowship and the impact the Program had on their classroom teaching and on the need of teaching critical thinking skills.

Procedures

The study employed a survey. The survey instrument was comprised of 23 4-point Likert response items (strongly disagree to strongly agree) based on seven dimensions: impact on critical thinking, use of technology in the classroom, influence on curriculum, improved teaching behaviors, application of critical thinking skills, logistics regarding the Christa McAuliffe Fellowship Program, and improving promotion of the Fellowship Program. The responses were converted from the verbal options (strongly disagree, disagree, agree, and strongly agree) to numerical indicators (1, 2, 3, and 4 respectively). Thus, a response of “1” would represent strong disagreement with a statement, a response of “4” would represent strong agreement with an item, and an average response of 2.5 would represent neither agreement nor

disagreement. Respondents were also given the opportunity to indicate that an item was not applicable. In addition to the 23 Likert items, the survey form included seven demographic items regarding gender, tenure classification, age, experience in current position, education, total experience, and number of students enrolled at their schools.

The survey was sent to all 517 recipients of the Christa McAuliffe Fellowship for its first 10 years (1987-1997). Completed surveys were received from 317 recipients for a 61% return rate. The data were hand-entered into a computer spreadsheet and checked for accuracy. Complete data were submitted by 217 respondents and usable data were submitted by 99 more respondents for a total of 316 or 61% usable surveys.

First, analyses were conducted to verify the reliability and validity of the survey instrument itself. The seven dimensions were verified using principal components analysis, a statistical grouping process. Item analyses and coefficient alphas (internal consistency indices) were computed for each dimension to establish the reliabilities.

Following the item reliability and validity analyses, the data were analyzed in two ways. First, the individual items were analyzed, computing the means, standard deviations, and confidence intervals for each item. Second, differences in seven dimension scores were compared across the demographic variables of gender, tenure, age, experience in current position, total experience, level of education, and size of enrollment. In order to consider these differences simultaneously, the data were analyzed using multivariate analyses of variance (MANOVAs).

Specifically, differences in the seven dimensions of the instrument were compared across the levels of gender, tenure status, age, experience, degree, and school enrollment as independent variables in separate analyses.



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Results

The results were first analyzed on an item-by-item basis. Table 1 lists the individual items in order of magnitude of the means from the item with the largest mean to the item with the smallest mean. For an individual item, a mean response of 1.00 would indicate that all respondents “strongly disagreed” with the statement. A mean response of 4.00 would indicate that all of the respondents “strongly agreed” with the statement. A mean response of 2.50 would indicate that, on the average, the respondents were neutral with respect to their agreement with the statement. Table 1 also includes 95% confidence intervals for each item; that is, the probability is 95% that the mean response to an item is between the lower and upper confidence limits. Thus, two items can

be considered significantly different if their confidence intervals do not overlap.

The two items with the largest means were “An experiential (hands-on) approach to teaching should be part of every classroom.” (mean = 3.82) and “I improved my knowledge, skills, and abilities as a classroom teacher as a result of receiving the Christa McAuliffe Fellowship.” (mean = 3.80). These two items were not significantly different from each other, but their means were significantly larger than those for all other items. Conversely, the item with the smallest mean, “The U.S. Secretary of Education should select one ‘educational theme’ as priority each year.” (mean = 1.74 on 5-point scale) was significantly smaller than all other items.

Before examining the individual dimensions, it is important to verify their reliability and validity. The principal component analysis confirmed that seven dimensions were present in the instrument and the appropriate items were included in each dimension. The dimensionality of the instrument was supported by the Kaiser Criterion (or “eigenvalue greater than one” criterion) and the Cattell Screen Test, both standard indices used for determining dimensionality. Item membership in each dimension was confirmed through a principal factor analysis with varimax rotation. Every item but one correlated at least .50 with a specific dimension. Table 2 presents the items from the survey grouped within their dimensions and each item’s correlation with its dimension. In addition, the means and standard deviations for the items are presented. One item, “I believe every Christa McAuliffe Fellow should understand Christa McAuliffe’s commitment as a classroom teacher and the conditions of

Table 1. Survey Items with Means and Confidence Intervals by Order of Magnitude

Item	Mean	95% Confidence Interval
An experiential (hands-on) approach to teaching should be part of every classroom.	3.82	3.77-3.87
I improved my knowledge, skills, and abilities as a classroom teacher as a result of receiving the Christa McAuliffe Fellowship.	3.80	3.75-3.85
A creative environment is a necessary ingredient for teaching thinking and reasoning skills.	3.74	3.69-3.79
I believe every Christa McAuliffe Fellow should understand Christa McAuliffe's commitment as a classroom teacher and the conditions of this national award.	3.72	3.67-3.77
My receipt of the Christa McAuliffe Fellowship caused curriculum change in my class.	3.63	3.56-3.70
The Christa McAuliffe National Fellowship Program should be awarded only to outstanding full-time teachers.	3.56	3.48-3.64
I improved my ability to teach critical thinking skills to my students as a result of receiving the Christa McAuliffe Fellowship.	3.47	3.39-3.55
The use of space related technologies by teachers in the classroom enhances students' opportunities to live, work, and succeed in an internationally competitive society.	3.47	3.40-3.54
As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>interpretation</i> critical thinking skill.	3.31	3.24-3.38
As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>inference</i> critical thinking skill.	3.30	3.22-3.38
My receipt of the Christa McAuliffe Fellowship influenced curriculum change in my school.	3.28	3.18-3.38
Immediate aerospace technology transfer to the classroom environment would be useful to motivate students.	3.28	3.21-3.35
As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>deduction</i> critical thinking skill.	3.23	3.15-3.31
As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>evaluation of arguments</i> critical thinking skill.	3.19	3.11-3.27
As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>recognition of assumptions</i> critical thinking skill.	3.12	3.04-3.20
Spin-offs from space technology and other high technology research are important to my method of teaching (e.g., uplink/downlink satellites, microwaves, personal computers, robotics, laser devices, optical information storage devices, etc.)	3.11	3.01-3.21

Table 1. Continued

Item	Mean	95% Confidence Interval
Federal and state regulations (red tape) required to ensure proper expenditure of the Christa McAuliffe Fellowship were minimal.	3.02	2.92-3.12
Space related classroom activities have had a significant, positive effect on the thinking and reasoning skills of my students.	3.01	2.92-3.10
My receipt of the Christa McAuliffe Fellowship influenced curriculum change in school system.	2.93	2.82-3.04
A major difficulty with the United States educational process is the inability of teachers to teach students how to think, reason, and apply knowledge.	2.92	2.82-3.02
The regulation that states that fellowships awarded may not exceed the average national salary of public school teachers in the most recent year is an appropriate amount for the purpose of the Fellowship.	2.91	2.82-3.00
The Christa McAuliffe Fellowship Program is promoted in my school system (LEA and/or school) as an important program for classroom teachers.	2.29	2.18-2.40
The U. S. Secretary of Education should select one "educational theme" as priority each year.	1.74	1.65-1.83

Table 2. Survey Items in Each Dimension, Correlations with Dimensions, Means, and Standard Deviations

Dimension	Item	Correlation with Dimension	Response Mean \pm SD
1. Impact on critical thinking	• As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>inference</i> critical thinking skill.	.79	3.3 \pm .69
	• As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>recognition of assumptions</i> critical thinking skill.	.88	3.1 \pm .69
	• As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>deduction</i> critical thinking skill.	.88	3.2 \pm .66
	• As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>interpretation</i> critical thinking skill.	.86	3.3 \pm .67
	• As a result of the Christa McAuliffe Fellowship, my teaching methods include more exercises and experiences that require the <i>evaluation of arguments</i> critical thinking skill.	.86	3.2 \pm .72

Table 2. Continued

Dimension	Item	Correlation with Dimension	Response Mean \pm SD
2. Use of technology in the classroom	• Spin-offs from space technology and other high technology research are important to my method of teaching (e.g., uplink/downlink satellites, microwaves, personal computers, robotics, laser devices, optical information storage devices, etc.).	.76	3.2 \pm .84
	• The use of space related technologies by teachers in the classroom enhances students' opportunities to live, work, and succeed in an internationally competitive society.	.76	3.5 \pm .55
	• Space related classroom activities have had a significant, positive effect on the thinking and reasoning skills of my students.	.83	3.1 \pm .73
	• Immediate aerospace technology transfer to the classroom environment would be useful to motivate students.	.62	3.3 \pm .57
3. Influence on curriculum	• My receipt of the Christa McAuliffe Fellowship influenced curriculum change at my school.	.88	3.3 \pm .87
	• My receipt of the Christa McAuliffe Fellowship influenced curriculum change in my school system.	.90	3.0 \pm .92
4. Improved teaching behaviors	• I improved my knowledge, skills, and abilities as a classroom teacher as a result of receiving the Christa McAuliffe Fellowship.	.85	3.8 \pm .48
	• I improved my ability to teach critical thinking skills to my students as a result of receiving the Christa McAuliffe Fellowship.	.71	3.4 \pm .68
	• My receipt of the Christa McAuliffe Fellowship caused curriculum change in my class	.70	3.6 \pm .67
5. Application of critical thinking skills	• A major difficulty with the United States educational process is the inability of teachers to teach students how to think, reason, and apply knowledge.	.55	3.0 \pm .86
	• A creative environment is a necessary ingredient for teaching thinking and reasoning skills.	.66	3.8 \pm .42
	• An experiential (hands-on) approach to teaching should be part of every classroom.	.64	3.8 \pm .39
6. Logistics regarding the Christa McAuliffe Fellowship	• The Christa McAuliffe National Fellowship Program should be awarded only to outstanding full-time teachers.	.64	3.6 \pm .69
	• Federal and state regulations (red tape) required to ensure proper expenditure of the Christa McAuliffe Fellowship were minimal.	.57	3.0 \pm .85
	• The regulation that states that fellowships awarded may not exceed the average national salary of public school teachers in the most recent year is an appropriate amount for the purpose of the Fellowship.	.59	2.9 \pm .81

Table 2. Continued

Dimension	Item	Correlation with Dimension	Response Mean \pm SD
7. Improving promotion of the Fellowship Program	• The Christa McAuliffe Fellowship Program is promoted in my school system (LEA and/or school) as an important program for classroom teachers.	.52	2.3 \pm .93
	• The U.S. Secretary of Education should select one “educational theme” as priority each year.	.81	1.7 \pm .80

this national award,” did not correlate .50 with any single dimension, but did correlate .36 and .39 with Dimensions 5 and 6 respectively.

Analyses of the individual items indicated that all items were appropriately related to their respective dimensions. The internal consistency reliable (coefficient alpha) for each dimension is presented in Table 3. It was concluded that only the first four dimensions were sufficiently reliability to use in further analyses. The first four dimensions were “impact on critical thinking,” “use of technology in the classroom,” “influence on the curriculum,” and improved teaching behaviors.” However, this does not mean that the individual items comprising the other three dimensions are invalid. The individual responses and means as presented in Table 1 still have much to contribute. The standard deviation represents an index of agreement. Agreement among the respondents is proportional to the standard deviation of an item. In general, the responses of approximately two-thirds of the respondents fall within one standard deviation of the mean.

For Dimension 5, applications of critical thinking skills, the means were at the “agree” level (“A major difficulty with the United States educational process is the inability

of teachers to teach students how to think, reason, and apply knowledge,” mean = 3.0) or near the “strongly agree” level (“A creative environment is a necessary ingredient for teaching thinking and reasoning skills” and “An experiential (hands-on) approach to teaching should be part of every classroom,” had means = 3.8). All three items in Dimension 6, logistics regarding the Christa McAuliffe Fellowship Program, had means at or near the “agree” level (3.6, 3.0, and 2.9 for Items “The Christa McAuliffe National Fellowship Program should be awarded only to outstanding full-time teachers,” “Federal and state regulations (red tape) required to ensure proper expenditure of the Christa McAuliffe Fellowship were minimal,” and “The regulation that states that fellowships awarded may not exceed the average national salary

of public school teachers in the most recent year is an appropriate amount for the purpose of the Fellowship,” respectively). Dimension 7, improving promotion of the fellowship program, had the lowest means of all the items with both being below the “neutral” level. That is, on the average, respondents did not believe that the fellowship program was promoted at their schools and they did not believe that the U.S. Secretary of Education should select an educational theme for the program each year.

The four reliable dimensions were compared across the levels of the demographic variables using MANOVAs. The results are presented in Table 4. As can be seen in Table 4, the four dimensions are not significantly related to gender, tenure status, current classroom experience, total classroom experience, level of

Table 3. Reliability of Each Dimension

Dimension	Reliability (Coefficient Alpha)
1. Impact on critical thinking	.94
2. Use of technology in the classroom	.77
3. Influence on curriculum	.86
4. Improved teaching behaviors	.71
5. Application of critical thinking skills	.40
6. Logistics of fellowship program	.35
7. Promotion of fellowship program	.20

Table 4. Multivariate Analysis of Variance Results Where

Independent Variable	<i>F</i> -Statistic	<i>F</i> -Probability	Eta Square
Gender	1.07	.375	.020
Tenure Status		1.29	.276
Age		1.27	.231
Experience in Current Position		.78	.669
Total Experience		.67	.781
Level of Education		1.18	.274
Enrollment at Current School		1.27	.176

Note. Dimensions 1, 2, 3, and 4 from Table 3 are dependent variables.

degree, or school enrollment. This is true whether considering statistical significance (minimum significance level is $p = .231$) or practical significance (maximum variance of a dependent variable accounted for by an independent variable is .026 or 2.6%). These results were cross-validated for the dichotomous variables of gender and tenure status using an second statistical method, logistic regression.

Discussion and Conclusions

Christa McAuliffe Fellowship recipients perceived the program to have impacted their effectiveness as science teachers. Specifically, they perceived the awarding of this Fellowship to have improved their ability to produce critical thinking in students, use technology in the classroom, improve the curriculum, improve teaching behaviors, and help students apply critical thinking skills. Collectively, these dimensions demonstrate the perceived impact the Christa McAuliffe Fellowships have had in the United States over a 10-year period and continue to have in the 21st century. Moreover, the recipients of the fellowship overwhelmingly agreed with the positive statements

regarding the program’s impact on their knowledge, teaching, and curriculum.

Fellowship recipients strongly agreed with most of the items and agreed, on the average, with all but two items. They agreed most strongly with items dealing with (1) experiential learning being part of every classroom and (2) receiving the Christa McAuliffe Fellowship as having improved their abilities to improve students’ critical thinking skills. Award recipients disagreed with the idea that the U.S. Secretary of Education should select one “educational theme” as a priority each year and, to a lesser extent that the Christa McAuliffe Fellowship Program is promoted in their school systems.

Space still has a fascination for most students and this fascination can be used to motivate them to learn the principles behind the science.

It is interesting that the study did not find relationships between the four valid dimensions on the survey and gender, tenure status, classroom experience, age, education level, or size of school. This suggests that opinions of the program’s effectiveness are independent of these variables. If this finding was confirmed through additional study, it would suggest that a strength of the program is its ability to transcend the variables of gender, experience, etc. This finding is supported very strongly in this study by the lack of both statistical and practical significance.

The findings of this study indicate that Christa McAuliffe Fellowship recipients believe that science teachers could benefit from similar sabbatical experiences which allow them time and resources to develop knowledge, skills, and abilities related to these dimensions. The broader conclusion is that space related information could provide a vehicle for motivating and explaining science to students. The recipients agreed that their involvement in this program influenced curriculum change not only in their own classrooms, but also in their schools and school systems. Space still has a fascination for most students

and this fascination can be used to motivate them to learn the principles behind the science. Further, it lends itself to hands-on activities to further enhance learning.

Although 17 years have passed, Christa McAuliffe's dream continues to live and influence classroom teachers and students throughout America. On February 1, 2003, the STS-107 Columbia and Crew recorded another tragedy while returning from orbit. Although their mission pushed the space frontier forward, the ultimate price was paid. As with the Apollo 1 and Challenger, the world grieves for the human loss. However, all three crews will be remembered as they boarded their ships: with their hearts and minds filled with hope and expectations for a better world because of their bold explorations and research. And, their contributions to humankind will continue to be appreciated by those who love and understand their willingness to accept the risk inherent in every mission. Ironically, this disaster has, once again, focused attention on the space program and the courage of those who pursue it. Whether in the teacher's classroom, or in the classroom without walls of the world, each astronaut's dream will live on through the people they represented and served—just as Christa McAuliffe's dream continues to live through teachers and students influenced by the Christa McAuliffe Fellowship Program.

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Engaging Stakeholders in Productive Meetings to Reform Science Education

A course is described which prepared graduate students to engage stakeholders in productive meetings to reform science education and to prepare for future leadership roles in science teacher education reform.

Have you ever spent hours in a meeting in which you thought progress had been made only to come back to a follow-up meeting and find yourself addressing the same issues as if they had never been discussed before? Leaders all over the United States have been experiencing this ever since funding agencies and other political institutions began requiring active participation from multiple stakeholders in science education decision-making to forward the reform of our enterprise.

This paper presents suggestions for leaders in science education to assist in developing effective stakeholder groups contributing to the reform in science education. In this political climate initiatives to reform science teacher education and science education for students K-16 are expected to involve stakeholders from a variety of sectors in schools, universities, and the community. Facilitating the organization and work of such groups usually falls to the current leaders in science education in schools, state agencies, and universities. The diverse backgrounds of the various stakeholders are a double-edged sword. On one hand, they provide new ideas from which to develop creative programs. On the other hand, the varied perspectives that enrich the base of ideas

also create enormous communication barriers that often impede progress. “Understanding the multitude of perspectives held by the varied stakeholders in science education is essential to ensure that all of us work toward common goals” (Spector, Strong & King, 1996). Leaders, therefore, need to be prepared with an armamentarium of techniques to orchestrate the work of stakeholders.

“Understanding the multitude of perspectives held by the varied stakeholders in science education is essential to ensure that all of us work toward common goals.”

The suggestions offered herein emerged from a grounded theory study (Erickson, 1998; Glaser & Strauss, 1967; Jacobs, 1987) of an exercise in facilitated stakeholder discussion aimed at creating an ideal science teacher education program consistent with today’s national goals. The findings are applicable to developing

science programs for school students as well. This exercise was conducted in a university doctoral course. Deriving recommendations for ways to facilitate human interactions in groups from studying students in university settings is common practice in the social sciences. The participants in the course constituted a microcosm of stakeholder groups at work throughout the nation in both informal and formal settings. Stakeholders included (a) a formal audience of educators—community college, university science educators, and scientists—science supervisors, teaching practitioners, research scientists, and education specialists, and (b) a community audience representing business, industry, youth development, and education and outreach (e.g. science enrichment programs, teacher workshops, and informal programs).

From this exercise two types of information were learned that are important for leaders when facilitating stakeholder interactions. First, several alternative processes of facilitation were initiated in this course setting in reaction to different forms of resistance. We report the types of techniques that were effective in addressing instances of resistance and fostering open and effective participation by all members of the stakeholder

community. Second, we offer several suggestions about how the lessons learned from this facilitation might be applied to professional development workshops and simulations that bring stakeholders together to develop reforms in science education. In the wake of 9/11 professional simulations are becoming a more common tool for professional development in the light of addressing crises. We suggest that similar types of exercises may be meaningful for developing techniques for science education reform.

Helping stakeholders assume the posture of learners is often a challenge.

The National Context

In the early 1990s the National Science Foundation (NSF) indicated there was an urgent need for stakeholder groups to work together collaboratively to design and implement reformed teacher education programs and created the Collaboratives for Excellence in Teacher Preparation (CETP) program to facilitate that reform. The NSF and the U.S. Department of Education began funding Math-Science Partnerships (MSP) and the associated Research Evaluation and Technical Assistance (RETA) in 2001, again requiring large scale, complex collaborations.

The National Institute for Science Education (NISE) (Mundry, Spector, Stiles & Loucks-Horsley, 1999) reported that stakeholders creating a shared vision for teacher education was a critical step toward making science

teacher education consistent with national and state goals for reform. The NISE study identified key issues (e.g. culture differences, entrenched roles) that needed to be addressed to reform teacher education and mechanisms (e.g., create shared vision, attend to communication and collaboration) being used by initiatives across the country to address the issues.

Senge (1990) and Novak (1998) stressed that for an organization to succeed, it has to become a learning organization. In such an organization, people work together to generate new knowledge. "... people at all levels are, collectively, continually enhancing their capacity to create things they really want to create." (p. 178). The range of understandings within a stakeholder group suggests that everyone in the group must engage in learning about each other's perspectives and goals and processes involved in reform, and work together in order to create a viable vision. Helping stakeholders assume the posture of learners is often a challenge.

An individual stakeholders' understanding of the meanings engendered in the major documents guiding the reform of science education influences what each stakeholder perceives should be the changes in education to make it consistent with national and state goals for reform. This diversity of perspectives and goals must be reconciled by creating one common vision to which everyone in the group will commit and work. Communication and collaboration are keys to creating that vision.

Two elements of the process for collaboratively creating a vision are establishing (a) an environment of trust and (b) a shared vocabulary (Spector,

A shared language is needed to facilitate "understanding of each other's worlds, strengths, capacities, constraints and operating norms."

Strong and King, 1996). Since stakeholder groups are composed of people with varied past experiences individuals can be expected to attach different meanings to the same words. A shared language is needed to facilitate "understanding of each other's worlds, strengths, capacities, constraints, and operating norms" (Mundry, Spector, Stiles & Loucks-Horsley, 1999). Significant time must be set aside in order to clarify and negotiate language issues and confront paradigm clashes when they surface (Spector & Brunckhorst, 1999; Simpson, 1997). It is common for stakeholders to underestimate the amount of time, energy, and complexity of the process to create a vision (Simpson, 1997). The need for research on ways to facilitate the process was documented by NISE (Mundry, Spector, Stiles, & Loucks-Horsley, 1999). The study herein responded to the need for additional research on the process of creating a common vision.

The importance of developing learning organizations, or learning communities, among stakeholders has been given great emphasis by the National Science Foundation (NSF) and the U.S. Department of Education in the recent development of the Math-Science Partnerships

It is common for stakeholders to underestimate the amount of time, energy, and complexity of the process to create a vision.

(MSP) and the associated Research Evaluation and Technical Assistance (RETA) grants. Great emphasis has been given to developing incentives designed to fostering reciprocal communication patterns between partner organizations. Similarly, the federal officers responsible for administering development of MSP's have emphasized that organizational change and learning are expected from all members of the learning community, not just the K-12 schools, if an effective learning community is to be developed. The importance of creating a shared vision is even greater as the sizes of the sponsored MSP learning communities are ambitious both in terms of the number and variety of participating organizations.

The Setting for Facilitation

We studied alternative approaches to facilitating the development of a shared vision through a doctoral class composed of individuals representing many perspectives found in typical stakeholder groups. The learning opportunity was structured to provide students with experience functioning as stakeholders faced with the same challenges as other stakeholders in teacher education reform initiatives around the country.

Doctoral students in this class perceived the course to be uniquely structured. It focused on solving a critical problem currently facing the science education enterprise: "How do we design a vision for a science teacher education program that would be consistent with current national goals?" The professor charged students with the responsibility to create options to solve the problem and made a variety of resources available. She intentionally chose not to take the stance of the authority. Instead, her role was as a member of a community of learners who were on an equal playing field. This style of leadership did not conform to students' expectations and there was significant resistance initially to the non-traditional role of the professor. This was reminiscent of resistance in stakeholders, who were brought together in funded projects, expecting the leader to have all the right answers to problems implementing a project.

Stakeholders here were participating in a formal learning opportunity (course) in which in-depth learning about reform was an explicit goal. This may be in contrast to other stakeholder groups who commonly do not start with learning as an explicit goal. The focus of the study was to (a) identify factors that influenced participation and interactions within a stakeholder group of doctoral students, and (b) identify techniques used to facilitate the process of creating a common vision. The intent of the course was to prepare doctoral students as change agents for leadership roles, aligning science teacher education with national and state goals.

Factors Affecting Stakeholder Interactions

Researchers identified ten factors from the analysis that influenced the way participants interacted, communicated and collaborated in the course. Some factors reflected the diverse prior experiences of individuals. Other factors emerged during the process of negotiating and creating a common vision as a stakeholder group. The following is a list of the emergent factors that affected willingness and the way in which individuals participated.

Prior knowledge and status gained from professional experience

1. teaching experience and setting in which it was gained
2. outside influences such as work loads, other commitments, and time constraints
3. prior knowledge and precepts regarding reform in science teacher education
4. beliefs about leadership—(there was some evidence of a natural hierarchy emerging in the group, however, this was discouraged in favor of community building and establishing a level playing field).
5. level of resistance to the belief that reform was a realistic goal

Social status effect from being graduate students in a program

6. standing in the doctoral program—for example, students who were further along in their studies started by being more confident in their assertions about science education (and life in general, if truth be told).

Personal comfort in a group setting

7. level of familiarity among individuals prior to entering this class
8. prior experience in a generative (student-driven) classroom
9. self efficacy regarding the value of his/her contribution to the group
10. level of resistance to open communication

Findings indicated that the difficulty of the task lay in people being willing to make enough of a shift in thinking/learning to construct meaning outside of their “prior experiences” box and collaborate as a learning organization. There was significant resistance initially from many students to the nontraditional role of the professor. Specific factors contributing to resistance were the individuals’ expectations of roles and how class should operate. These included prior experience in a generative classroom, self-efficacy regarding the value of his/her contribution to the group, and stage in the doctoral program.

Experience in their jobs also significantly influenced students’ participation in the task. They explicitly used prior knowledge from their respective positions (their jobs) as a) the starting point, and b) the constant reference point to solve the problem. The different points of view inherent in their positions revealed differences in beliefs about goals, paradigms, and use of language. Members of this class encountered the same barriers with which stakeholder groups in science teacher reform initiatives around the country were struggling. The barriers encountered required the need to build communication and collaboration skills in order to accomplish the task as a group. Students became aware

“How do we design a vision for a science education program that would be consistent with current national goals?”

that they could not succeed at the task by learning independently as they had traditionally done in classes, but instead needed to become a learning organization (Novak, 1998).

Interpretation of the links among the above factors affecting participation revealed five major issues that needed to be addressed to continue the task. These were the need to: 1) reconcile multiple perspectives and multiple goals, 2) build trust among the group members, 3) negotiate language and common vocabulary, 4) resolve paradigm clashes, and 5) develop effective communication skills. Recognizing these issues, in turn, led to the development and implementation of several facilitation techniques necessary to support the vision process for this group of stakeholder learners.

Specific facilitation strategies developed and implemented during the course

In general, the professor’s stance as a co-learner in the community, instead of the authority, contributed to various techniques emerging and being tested in response to preceding needs/issues that arose as the course progressed. Designing and implementing these techniques enabled students to develop a sense of ownership in solving the problem of developing a vision and thus ownership of the course. The

techniques also created a need for students to intentionally engage in active learning in order to benefit from, and incorporate, information from the resource material available. Ultimately, the strategies facilitated the group becoming a learning organization, willing and capable of designing a common vision for a teacher education program. Table 1 provides a summary of facilitation techniques utilized during this class.

Participants perceived their learning to be very practical as a result of the alternative course structure facilitated by these techniques. The structure provided a mechanism to apply the insights of reform documents to a real world problem with which they would have to deal as leaders, whether in university science education positions, school leadership positions, or from non-academic positions. Students as stakeholders during this course became empowered learners and communicators.

Selective Filtering of Information

Focusing the class on a real world problem at the outset affected the way many students read and interpreted the resources available to them. They perceived that they read the information available to them differently than they would have if they were just critiquing the documents to generate class discussions about reform in science teacher education. One student commented: “Looking at a document just to see what’s in the document, or what position a particular author takes on the subject, is different than looking at the document as the data source to solve a problem.”

Participants selectively filtered the information that seemed relevant to the problem at hand and went back to the resources on a need to know basis.

Table 1. Facilitation Techniques and Responses	
Facilitation techniques developed and implemented during this course.	Response to the techniques
Students were asked to generate the agenda for each class session that would facilitate the learning needed to design a science teacher education program consistent with national standards.	Each person examined the available resources, generated questions and posted them on the white board at the beginning of each class. These questions served as the agenda for the session.
A different student served as class facilitator each week.	This contributed to shared responsibility, shared leadership, and a level playing field.
A “round robin” approach to communication was used.	This encouraged all group members to contribute
Questions were used to gather information and clarify meaning in class. This is in contrast to questions being used to test whether someone had learned what he/she was supposed to have studied.	This encouraged intellectual risk taking and building a community of learners.
Synchronous face-to-face conversation during class and asynchronous messages via e-mail postings were used for intra-group communication.	The level of candor in each communication vehicle shifted as the semester progressed and students increased the depth of self-revelation and meaningful conversation. For the first quarter of the semester people seemed to be more willing to share their thoughts using e-mail than they were face-to-face in class. Later in the semester the class interaction became more dynamic and more open, with more risk-taking behavior evident. People were willing to question each other’s statements, to agree or disagree with each other’s ideas, and to synthesize new ideas into a group consensus.
A computer and projection system were used in class to record dialog. One student typed the salient points during the class discussions.	This helped to further the process of reaching group consensus. The words on the screen seemed to function as an intermediary for conversation. Instead of directly saying to someone, “I disagree with you”: students addressed comments to the screen. It appeared that as people focused on the words on the screen, they felt free to say, “No that doesn’t mean ... it should be said this way”. The words recorded during class were then posted on an e-mail. Communication continued asynchronously around the words until group consensus was finalized.
Each student developed a brief presentation about an aspect of reform related to his/her own competence and	Key aspects of these mini-projects were incorporated as part of the vision. Some examples were nature of science, use of time in schools, instructional computing, and patterns of communication. This resulted in each person being recognized as having special expertise that was valued by all. This is a characteristic essential to effective collaboration (Spector, Strong, and King, 1996).

Thus the problem created a perspective for filtering the information in the readings and constructing meanings within the context of the problem. For example, one student commented,

“Everything that we were reading we were reading from the perspective of gathering data that would help to solve a problem.”

How do these findings parallel other stakeholder groups?

This study identified four characteristics consistent with collaboration among other stakeholder groups. These were role expectations, leadership, cultural differences, and the amount of time allotted to fulfill a specific goal. Each of these characteristics is described below to illustrate specific examples within this study that parallel key elements identified in previous works (Mundry, S., Spector, B., Stiles, K. & Loucks-Horsley, S., 1999; Spector, B. & Brunkhorst, H., 1999; Simpson, 1998; Novak, 1998; NSF-CETP, 1998; Spector, Strong & King, 1996).

Role expectations.

Students’ role: Each stakeholder began the course with entrenched views about prescribed roles in a group context. Initially, students expected traditional roles for the professor and students. However, as the course progressed and the hierarchy flattened these role expectations were modified. An effective strategy to facilitate new role expectations was to assign each group member a different role during each class meeting (e.g. facilitator, recorder). Use of a computer projection system helped to facilitate group consensus and eventually a level playing field of shared contribution and leadership. Some student comments include:

- “I value the exchange as members of the group posit and defend their positions”
- “I am interested in the differences in program ideas between teachers and non-teachers”
- “Tonight, we were really expressing our individual assets and everyone offered a valuable component to the whole”

Professor role: The professor had a high tolerance for ambiguity and great faith in the group process. She had prior experience implementing generative classes and facilitating stakeholders’ groups. Her willingness to exercise patience and endure students’ frustrations (verbal and nonverbal), because she refused to assume the traditional authority role, was supported by her confidence that the group process would result in a meaningful learning experience for students. She did however acknowledge that her posture as co-learner on a level playing field with this group of students, most of whom she had not known before class, was a high-risk action. In response to exit memos in which students expressed insight and appreciation for something accomplished, she frequently wrote things like:

- “Your enthusiasm and level of participation are an important part of the process.”
- “Thanks for staying with it, the aha’s will surface as we continue.”
- “The process is slow and requires full-time but you will realize the value.”
- “Thanks for the encouragement as this is a high risk strategy I am undertaking.”

Leadership

The nature of leadership desired for this course was a shared responsibility rather than one spokesperson for all. However, shared leadership and equal contribution among all members took time to develop. The course began with one student initiating a self-assigned leadership role. However, as the class progressed and strategies were implemented to facilitate shared responsibility, most all group members began to contribute verbally during face-to-face meetings. Shared leadership in light of indirect communication (e.g. e-mail postings) developed sooner in the group than during face-to-face meetings. All members, except two, contributed regularly to the e-mail communications that augmented in-class discussions and served as a means of posting students on-going learning logs (e.g. readings, class process and reflections). Some student comments include:

- “I wish more people would voice opinions, I enjoy hearing what others think”
- “This class has taken on new momentum. It wasn’t just that I contributed but I actually had something to say.”

Cultural differences

The learning community for this class consisted of participants representing different prior experiences and learning cultures (e.g. teachers to scientist). Only one doctoral student was a full-time student; all others were employed full-time in teaching and/or scientific research. Individuals had different expectations derived from variations in their cultural background (e.g. formal training, other job experience, and life experience). Cultural differences

influenced by prior experiences with other doctoral classes and groups were most evident at the start of the course and continued mid-cycle. Following the implementation of the facilitation strategies of round-robin approach, rotating facilitators, and a stream of questions, the strength of this barrier lessened, although never completely dissolved.

- “Personally, I need more direction. Perhaps I will get more guidelines as the class progresses”
- “It is hard to be productive as there is such a broad range of educational backgrounds in this class and teaching experience. This is good in some ways but also has disadvantages”

Element of time

It took a great deal of time to genuinely understand what each individual was trying to express (e.g. the meaning of words derived from different perceptual screens). Clarity seemed to emerge when each individual was given time to expand on his/her conceptual ideas. Use of a round robin approach enhanced this process. Time for clarification also fostered meaningful interpretations of an individual’s contributions and added value to the group. Consequently, individuals experienced more self-efficacy as a valued contributor to the group. Although this process was time consuming it resulted in some of the most constructive group dynamics.

- “To be honest, the task ahead seems a bit overwhelming to me. I think we need to buckle our seat belts and hold on for a rough ride”
- “ It was great to take the time to expand on each individual’s conceptual ideas; although time consuming, I feel time well spent”

Implications for Science Education Reform

The course studied was a learning situation from which to derive suggestions for engaging stakeholders in productive meetings to reform science education. This course can serve as a model to help science education professors a) give doctoral students opportunities to learn to become productive participants in stakeholder groups, and b) provide an experiential base for students upon which they can build the skills they will need to facilitate stakeholder groups. The ultimate goal of this course was to prepare doctoral students for future leadership roles in science teacher education reform. Such roles will likely require them to organize and facilitate stakeholder groups to improve science education at all levels. The mechanisms that emerged to facilitate group problem solving may be helpful to anyone who wants to conduct a formal course or workshop that resembles a working group of stakeholders.

This type of facilitation need not be limited to doctoral education. These techniques can also be applied to professional development workshops and executive development simulation exercises. In these settings the task of facilitation is not limited to developing a single strategic vision. Rather, the goal is to identify the range of strategic visions held by stakeholders that can be effectively meshed into a viable program. A further goal of the facilitation is that stakeholders become more active and reciprocal in their participation as a means of learning the tendencies, strengths and weaknesses of their fellow stakeholders. Since 9/11 this type of simulation has been used to great effect in other areas such as public

health, emergency preparedness, and homeland security. The mix of doctoral students involved in this course and the level of their professional experience indicated that these types of facilitations may work to great effect in a non-academic professional development workshop.

Furthermore, these findings have potential to contribute to turning stakeholder groups into learning organizations. Specifically, this research provides additional evidence supporting the need for collaboration and communication among stakeholders and presents techniques for facilitating this valuable process. The present research also supports and is supported by extant literature on trust, communication, group dynamics and collaboration (Mundry, S., Spector, B., Stiles, K. & Loucks-Horsley, S., 1999; Spector, B. & Brunkhorst, H., 1999; Simpson, 1998; Novak, 1998; NSF-CETP, 1998; Spector, Strong & King, 1996).

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