Exploring the Professional Development Design Process: Bringing an Abstract Framework into Practice

Designing effective professional development programs requires a deliberate process in which careful consideration is given to numerous inputs into the framework design.

The improvement of student achievement in science education continues to be a top priority in the US. The National Commission on Mathematics and Science Teaching for the 21st Century writes: "The most direct route to improving mathematics and science achievement for all students is better mathematics and science teaching" (2000, p.7). Others agree, suggesting that investments aimed toward improving education should focus on the preparation and ongoing professional development of teachers and other educators (Darling-Hammond & McLaughlin, 1999). While few would argue with these observations, improving teaching is a complex undertaking faced with many challenges.

For example, demanding standards and changing demographics present challenges. Educating highly diverse students to meet much higher standards requires tremendous skills on the part of teachers. Teachers today need to provide a wide range of learning experiences connected to what a diverse student body knows, how they learn, and the content and structure of the disciplines (Darling-Hammond & McLaughlin, 1999; Ball & Cohen, 1999). Teachers need opportunities over time to deepen their understanding of how children learn science and to stay abreast of emerging technologies and research. Veteran and novice teachers alike need collegial arrangements that provide a structure through which they continually develop their expertise as teachers.

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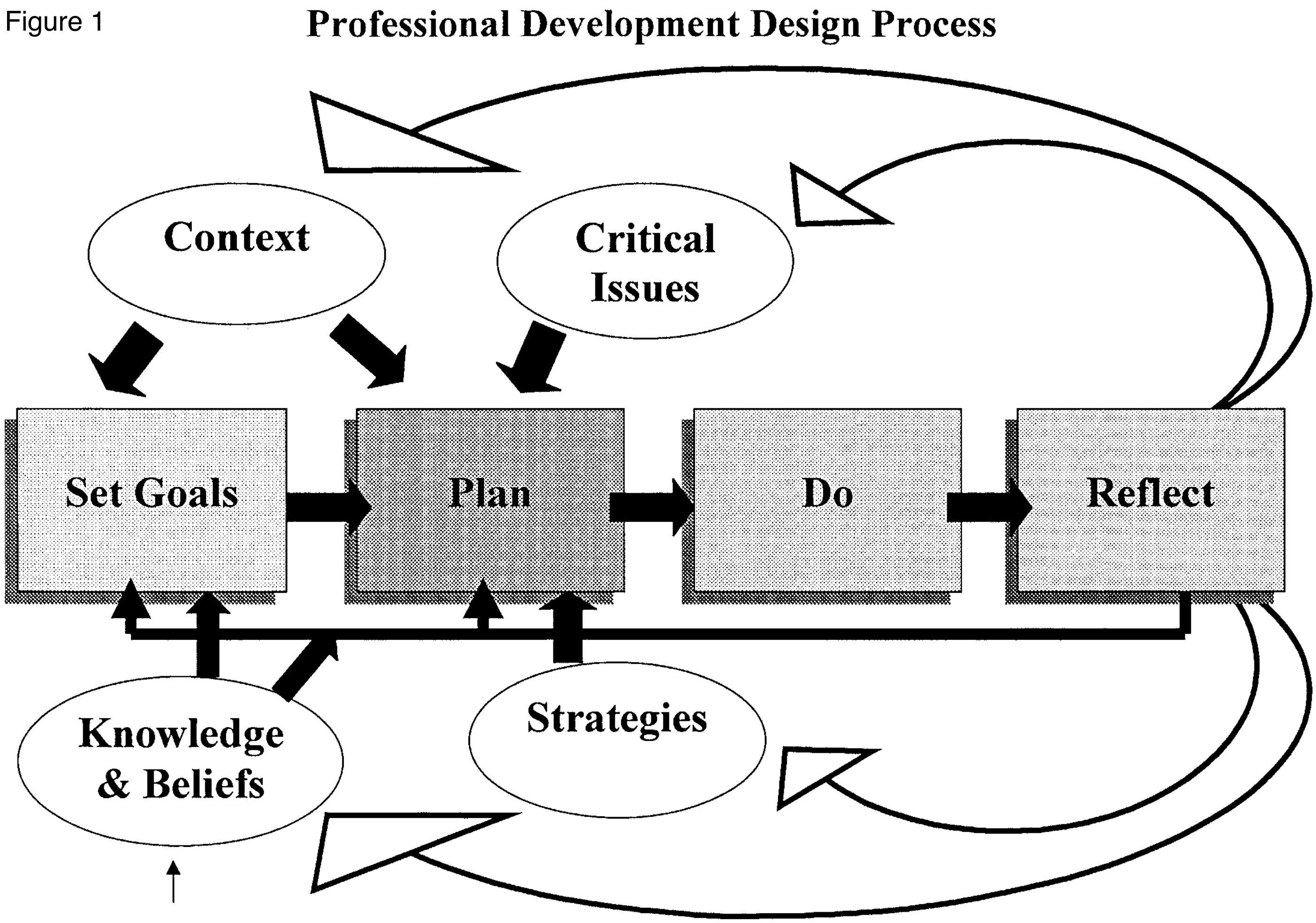
Professional development of teachers is clearly an essential element of science education reform.

All of the major improvement initiatives call for increasing teacher knowledge and skills because of the link between student achievement and teacher knowledge and skill. Research shows that teacher expertise can account for about 40 percent of the variance on students' learning in reading and mathematics achievement – more than any other single factor, including student background (Ferguson, 1991.) Other studies show a similar correlation between teacher expertise and student achievement across the subject areas.

Since teacher expertise has such a demonstrated impact on student learning, it stands to reason that programs that develop teachers' knowledge and skills are a sound investment in improving student outcomes. However, the research on learning (Bransford, et al., 1999) and that on effective teacher development (Sparks & Hirsch, 1997; Loucks-Horsley, Hewson, Love, & Stiles, 1998), suggests that teacher development as carried out in most schools today is not designed to develop the teacher expertise needed to bring about improved student learning. "The content of professional development is largely techniques, its pedagogy is training, and the learning it promotes consists of remembering new things to try in the classroom" (Thomson & Zeuli, 1999, p. 353).

Figure 1



From: Loucks-Horsley, S., P.W. Hewson, N. Love, & K.E. Stiles.
(1998) Designing Professional Development for Teachers of Science and Mathematics. Thousand Oaks, Calif.: Corwin Press

The professional development systems and structures in most schools need to be redesigned to develop and support capable, knowledgeable and expert teachers. One framework for designing professional development has informed the design and implementation of programs across the country. In the book, *Designing Professional Development for Teachers of Science and Mathematics* (Loucks-Horsley, et al., 1998), the authors describe a framework to guide the design of professional development programs. It is a process of decision making and conscious design based on several inputs (see Figure 1).

At the center of the framework is a planning cycle incorporating goal setting, planning, doing, and reflecting. The circles represent important inputs into both goal setting and planning that can help professional developers design programs to meet the needs of the audiences and that are grounded in best practice. The inputs guide designers to consider the extensive knowledge bases that inform their work (knowledge and beliefs), to understand the unique features of their own context, to draw on a wide repertoire of professional development strategies, and to incorporate designs to address the critical issues they are most likely to encounter. The arrows represent the continuous need to reflect: reflection can influence every input and is necessary since the design will continue to grow and change over time, resulting in the need to modify and adapt the existing design to meet the emerging needs of the program.

However, this is only a framework and bringing it to life requires "getting inside the developer's head" – exploring how individual designers struggle with each critical issue, examine their own beliefs and knowledge, consider the myriad combinations of strategies available to them, and carefully consider the contextual issues within which the professional development program will be implemented. This article is written with that goal in mind. One of the authors of the book, Katherine Stiles, interviews Jack Rhoton to explore how East Tennessee State University's PD Program reflects the process of designing effective professional development programs for science teachers.

Stiles: *In order to have a context for understanding the specific design of your professional development program for science teachers, describe the overall structure and the professional development strategies of the ETSU PD program.*

Rhoton: We've learned after more than a decade of working with science teachers and local school districts that short-term, one-shot workshops don't greatly enhance teachers' learning or the transfer of that learning into teachers' classrooms. Our current program is designed to provide ongoing professional development for teachers' professional growth and colleagueship.

First, the model emerging from this twelve-year partnership differs from traditional professional development paradigms in that it offers continued support and teacher training throughout the academic year. Second, it requires the simultaneous development of instructional skills, administrative insights, and content expertise. Third, it is a grass roots effort involving teachers who implement and maintain the changes. Subsequent to a two to six-week science leadership institute held on the ETSU campus during the summer, teachers return to their respective schools to implement the instructional innovation promoted by the program in the context of their own unique teaching arrangement. Feedback from teacher participants is used as a focus for planning and developing training institutes the following summer.

A two to six-week institute is typically held during the summer months. The mode of delivery during the intense summer institute consists of seminars and structured learning environments in which an accurate portrayal of content knowledge is presented in the context of inquiry and problem-solving strategies. Teachers and administrators engage in selecting and adapting curriculum to meet the needs of students. The institutes focus on content and pedagogy to produce teacher leaders and principals who are well trained to work with their colleagues. The appropriate usage of technologies, materials, and activities are interwoven throughout the institutes. As participants increase their knowledge of content and teaching strategies, they enrich the depth of their experience by exchanging, exploring, and reaching among themselves.

The institutes are developed around a theme that has been selected by the participants. The participants engage in learning experiences appropriate for their particular grade level or subject area. As part of these activities, visiting academicians and science educators develop participating teachers' requisite content knowledge, methodologies, teaching strategies and leadership skills for working with their peers.

Subsequent to the summer institutes, participants return to their respective schools to implement the science program. During this process, university science faculty provides ongoing support for participants during the academic year. These visits allow faculty to gather information from teachers and principals as they implement the professional development

Professional Development Strategies

- Immermsion:
  - Immersion into Inquiry in Science
  - Immersion into the World of Scientists
- Curriculum
  - Curriculum Implementation
  - Curriculum replacement Units
  - Curriculum Development and Adaptation
- Examining Practice:
  - Action Research
  - Case Discussion
  - Examining Student Work and Thinking, Scoring Assessments
- Collaborative Work:
  - Study Groups
  - Coaching and Mentoring
  - Partnerships with Scientists in Business, Industry, and Universities
  - Professional Networks
- Vehicles and Mechanisms:
  - Workshops, Institutes, Courses, and Seminars
  - Technology for Professional Development
  - Developing Professional Developers

model as well as to support teachers in their classroom environment. Participants in the program work with their peers by leading monthly science inservice training sessions, observe peer teachers and teach model science lessons, and assist peers in analyzing and selecting instructional materials for the classroom.

Stiles: *Your program reflects a combination of professional development strategies: summer institutes, academic year learning sessions, classroom observations, collaboration with scientist partners, and coaching and mentoring. One of the critical inputs into designing professional development is the knowledge and beliefs designers have about effective professional development. In your description, you indicate several goals: enhancing teachers' professional growth and colleagueship, and deepening teachers' science content knowledge and pedagogical content knowledge. What knowledge and beliefs about effective professional development led you to identify these specific goals and select the strategies that you implement?*

Knowledge and Beliefs

- Learners and Learning
- Teachers and Teaching
- The Nature of Science
- Professional Development
- The Change Process

Rhoton: There has been a proliferation of classroom and school based studies during the past two decades that have led to advances in approaches in professional development of science teachers. These advances have centered on complex challenges (e.g., subject matter standards, curriculum content, pedagogy, and assessment) in engaging science teachers in the kinds of study, investigation, and experimentation needed to identify and alter classroom practices that increasingly aspire to enhance students' scholastic growth. The knowledge base in professional development continues to grow as a range of professional development strategies are used and tested (Loucks-Horsley, et al., 1998). Recognizing that teachers serve as a critical link between the science curriculum and their student, professional development is an essential element in the development of teacher leadership skills (Rhoton, 2001). For example, several major documents have highlighted the central role professional development plays in science teaching and learning, including the National Science Education Standards (National Research Council, 1996) and Blue Prints for Reform in Science, Mathematics, and Technology (AAAS, 1998).

Even though we are beginning to learn what science teachers' professional development in a climate of science education reform should look like, the traditional training model dominates the science education landscape. Short-term, skill-training sessions and one-shot workshops far outnumber well-planned and executed professional development programs conceived in teacher research. Critics of the traditional methods of professional development charge that teachers are too often placed in a training paradigm that is fragmented in content, form, continuity and out of step with current science education reform (Sparks & Loucks-Horsley, 1990; Kyle, 1995; Lieberman, 1995). The new perspective on professional development demands a greater facility among teachers for integrating science content, development of effective learning environments, and organizing students' opportunity to learn (Loucks-Horsley, et al., 1998). The emerging strategies of professional development represent a challenge to the traditional professional development model in the context of present reform.

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Based on our long history of partnering with local education agencies to provide professional development, research on professional development and how teachers learn, and practice-based experience, we know that the most effective professional learning experiences for teachers are those that are grounded in teachers' practice. This necessarily includes a deeper understanding of the science content knowledge, an understanding of the ways in which students learn science, and the critical on-going support teachers need to implement new teaching practices in their classrooms.

Stiles: *In essence, you designed your program around the belief that professional development should be ongoing and extend over time, collaborative in nature, embedded in teachers' practices and needs, and systemic and supported. Other aspects of the program also reflect your knowledge and beliefs about effective professional development. For example, in your description, you imply that teams participate in the professional development program. Why do you include both classroom teachers and administrators in the program?*

Teachers at different stages in their teaching career will require professional development to meet their specific needs.

Rhoton: Actually, there are seven prerequisites for participation in the program, all of them grounded in our firmly held beliefs about effective professional development.

First, the principal of each participating school should participate as co-equals with the teachers in the program (principals participated in the K-6 institutes only). There are the matters of teacher time, structural arrangements, cultural norms, and professional development to support teacher learning, all of which affect student learning, either directly or indirectly. The principal who recognizes the crucial importance of school-and district-based initiatives can use his or her influence, power, and authority to help shape these variables. *Second*, the program should address issues of concern recognized by teachers themselves, including both content and pedagogy. One-size-fits-all professional development does not, in fact, meet the needs of all teachers. Teachers at different stages in their teaching career will require professional development to meet their specific needs. Teacher perceptions about student learning, confidence in subject matter understanding, and pedagogical beliefs will affect student learning.

Third, scientists from biology, chemistry, and physics should participate fully in the partnership. Content specialist can help teachers learn science in new ways and to assist teachers in reorganizing and refining their content understanding that supports standard-based practices. These experiences allow teachers to genuinely address change and renewal and reach beyond the "make and take" workshop session to more global, theoretical conversations that focus on teachers' understanding of the processes of science teaching and learning and of the students they teach. *Fourth*, the program must be connected to classroom practices. Like their students, teachers learn best when they are actively engaged in the learning process and take on the role of the student. Effective teaching practices should be modeled to teachers just as the teacher should model effective teaching to their own students. As teachers assume the role of the student, they are better prepared to implement the strategies with their own students. *Fifth*, the program should provide instruction in needs-assessment and program development to enable participants to design projects to meet their own needs. Even though anecdotal evidence may be useful in some situations, it does not provide defensible criteria to determine the program's value, utility, or significance to the intended change. When evaluation uses inquiry techniques, it is more likely to lead to recommendations in relation to the intended purpose(s) of the innovation.

Sixth, the program should encourage collaboration through team leadership development. Teachers consistently rank professional development activities that take place close to the working environment as the most important. Isolation and autonomy in schools have the potential to undermine collegiality among teachers. As teachers become aware of peers' classroom practices, they are more likely to develop the confidence to critically analyze their own work and ideas. Effective profes-

Isolation and autonomy in schools have the potential to undermine collegiality among teachers.

sional development programs involve teachers in the sharing of knowledge with a focus on building teachers' communities of practices rather than focusing on the efforts of individual teachers. *Seventh*, a field support system should be in place to assist the teams in implementing their program and providing training for other teachers in their schools. The model allows for teachers to work together, rather then perpetuating isolation. It allows for teachers to visit other classes, participate in training sessions, and teach cooperatively. It is for this reason that the principal is an integral part of the program. Principals are trained to make those structural changes that include physical space facilities and schedule changes to make it possible for teachers to effectively implement the science curriculum.

Stiles: *It is clear that ETSU has not embarked on implementing this program alone. You have other partners and resources involved in the project. Some of the context inputs into designing professional development are a focus on the organizational structures, the history of professional development in the organization, and the resources available through the community. You mentioned that you have a decade-long history of collaborating with local education agencies to provide professional development for science teachers. How does this program incorporate the numerous relationships you have established and nurtured over the years.*

Also, a major asset of the project's activities has been to establish collaborative relationships with educational institutions and other groups interested in improving pre-college science teaching and learning.

Context

- Students
- Teachers
- Practices
- Policies
- Resources
- Organizational Culture
- Organizational Structures
- History of Professional Development
- Parents and Community

Rhoton: With financial assistance from local education agencies, the Westinghouse Foundation, the Tennessee Higher Education Commission, the National Science Foundation and most recently, the Howard Hughes Medical Institute, ETSU has served as a partner in training more than three hundred teachers and administrators in the region's schools.

East Tennessee State University worked as a partner with science consultants, local science teachers and school administrators to develop the professional development model. The levels of success achieved in the numerous inservice and professional activities conducted by the graduates of Science Education Leadership Institutes could not have been accomplished without the administrative support and understanding that came from the central involvement of the building principal. Also, a major asset of the project's activities has been to establish collaborative relationships with educational institutions and other groups interested in improving pre-college science teaching and learning. Universities and school districts are encouraged to cooperate in the development of programs to provide joint preparation of teachers and principals for leadership roles in the improvement of science education. It is an alternative that should be considered as the nation's educational institutions continue to address the issues of science education reform.

Stiles: *You've already highlighted several critical issue inputs into designing professional development: building a professional culture, developing leadership, and supporting standards and frameworks. Another critical issue in the design of professional development is the evaluation of the overall program. In what ways have you collected data about the effectiveness of the program and what have you learned?*

Rhoton: As I noted earlier, participants in the program work with their peers by leading monthly science inservice training sessions, observe peer teachers and teach model science lessons, and assist peers in analyzing and selecting instructional materials for the classroom. The data collected from these activities reveal the following outcomes: training and teacher support occurring over an extended period of time, selecting and adapting curriculum to meet individual needs of teachers and students, networking of teachers with the principal, increased collaboration between teachers in the school, development of leadership qualities, and growth in guiding students in active scientific inquiry.

Perhaps the most immediate benefit to the sponsoring school districts was the increased instructional and curricular skills and content mastery of the team members. Data on performance in science content were gathered through pre- and posttests for each institute. Although participant performance varied in the institutes conducted from 1989 through 2000, the project group as a whole showed significant gains ($p < .01$ of approximately 12% in content mastery). The greatest gains were observed in physical science (9.6%) and earth and space science (14%); and gains of 9% in life science. However, the ultimate criterion for success of any education program is student performance. To evaluate this dimension of the program effect, comparison studies of students taught by institute teachers with students from the same grade level taught by other teachers in the same school who did not participate in the institutes extended over a six year period (1991-1997). Baseline data were gathered on student science mastery each fall. Pretest data on the performance of Institute groups were analyzed across grade levels by using a series of t-tests to compare the mean content score of each group with each other group. Posttests were administered near the end of the year, and the same comparisons were carried out on these data to assess student gains ($p < .01$ in most cases, and $p < .05$ in others). As a group, the Institute students made larger gains than students taught by teachers who did not participate in the institutes. Perhaps the greatest benefits, however, was that the schools found within their own ranks the leadership needed to find and follow a new direction in science teaching.

Critical Issues

- Ensuring Equity
- Building Professional Culture
- Developing Leadership
- Building Capacity for Professional Learning
- Scaling Up
- Garnering Public Support
- Supporting Standards and Frameworks through Professional Development
- Evaluating Professional Development

Conclusion

The PD Program at ETSU clearly exemplifies many of the decision-making processes engaged in by the professional developers as they designed the program for teacher learning and classroom teaching. Obviously there are numerous aspects of the design framework that were not explored in this article. However, this brief look into the deliberate process of designing professional development – considering the numerous inputs into the design – helps bring an abstract framework into the practices of those who continue to work diligently to improve science teaching and learning in our schools.

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Brian Drayton, Joni Falk

Inquiry-oriented Science As a Feature of Your School System: What Does It Take?

Key characteristics of the inquiry-based science classroom are described in the context of both school and district.

At present, much of the discussion of science education is cast in terms of the national or state standards, and the associated accountability movement. Yet behind the policy debate are long-standing challenges for science educators, such as: What is the right thing to teach? How best shall we teach it, in what order, and to what level? How shall we recognize successful learning of science? What skills and characteristics are needed for a good science teacher? The current movement to define and implement curriculum standards has adopted "inquiry" as one critical component of a strategy for an effective program of science education. In responding to standards mandates, schools, districts, and teachers across the country have been engaged in an arduous process of interpretation and implementation. What does "inquiry" mean? What will it demand of the teachers and students? What kinds of curriculum will support it? How is it to be assessed?

In the course of a research project on middle-school science teachers' interpretations and implementation of inquiry mandates,[1] we have come to see that these questions must be joined by others which probe the school and district cultures which are the "atmosphere" within which science classrooms live. In this article, we draw on our own and others' research to situate key characteristics of the inquiry-based classroom in the school and district context. If the systemic nature of science education is not borne in mind, we suggest that the solutions which the inquiry approach can contribute to the perennial challenges of science education will not get a fair trial in actual practice, and thus join the parade of partial reforms that litter the landscape of American education.

In this paper, we briefly characterize key features of the inquiry strategy, and discuss important characteristics of an inquiry-oriented classroom. We address how the school and district climate can shape the implementation of inquiry in the classroom, either supporting or hindering this complex and urgent innovation.

1. The inquiry strategy

The inquiry strategy has three root ideas. The first is a view of the subject matter: What is the science to be learned? The second is a view of the learner: How does learning proceed?

In responding to standards mandates, schools, districts, and teachers across the country have been engaged in an arduous process of interpretation and implementation.

If the systemic nature of science education is not borne in mind, we suggest that the solutions which the inquiry approach can contribute to the perennial challenges of science education will not get a fair trial in actual practice, and thus join the parade of partial reforms that litter the landscape of American education.

Inquiry-based science is a strategy for addressing this challenge, by placing a high emphasis on the *depth* of conceptual learning, rather than on the remembering of the *results* of science…

The third is a view of the teacher: How does the teacher facilitate the growth of science understanding?

What is the science to be learned? Anyone promulgating a science curriculum faces the challenge of science as a body of knowledge. Science is vast and growing, not one field but many. Furthermore, the results of scientific investigation mount up — it is commonplace to talk about the "exponential growth" of scientific information. The problem of how to determine the "right" scope and sequence of content in the curriculum finds repeated solutions – one after another in successive waves of reform. The intractability of the challenge is not new – Dewey noted it in 1910:

> "One of the most serious difficulties that confronts the educator who wants … to do something worthwhile with the sciences is their number and the indefinite bulk of the material in each … There is at once so much of science and so many sciences that educators oscillate, helpless, between arbitrary selection and teaching a little of everything." (Dewey 1910)

Inquiry-based science is a strategy for addressing this challenge, by placing a high emphasis on the *depth* of conceptual learning, rather than on the remembering of the *results* of science (Drayton and Falk 2000, NRC 2000); the key here is making the tools and methods of knowledge creation a core part of the curriculum. Only thus can we overcome the problems risked by basing science education on a particular curriculum's choice of what is fundamental and necessary to know, out of a vast range of possibilities. It also overcomes an inherent problem with science, which is the rapid growth of factual information, and the frequent revision of previous findings. The classroom approach to specific topics (plate tectonics, kinematics, stoichiometry, the cell) must be conceptual, and grounded in questions, evidence, reasoning, observation, and other key processes, as each takes a characteristic form in the particular topic area being addressed. This approach values learning in depth as opposed to broad "coverage" of topics. The number of possible topics is growing rapidly, so the inquiry strategy is to build strong qualitative and quantitative understanding, which provides a lasting mastery of scientific habits of mind.

This characteristic focus is ill-represented by the sound-bite summary, "process versus content." The inquiry-based approach at its most developed eliminates this dichotomy in two ways. First, it adopts the view of science as it is actually practiced: science as the webs of explanation (theory) by which we seek to make sense of the phenomena of the world (Latour and Woolgar 1986; Hawkins 1965). Thus, the learning of content is embedded in an explanatory context, which has its roots in questions and methods for answering them. Second, it sees that a fundamental goal of science education is helping the child come to see how questions, predictions, reasoning and reflection about evidence (data) and the use of investigative methods are an intrinsic part of the changing fabric of conjecture and theory which is scientific knowledge (Driver et al. 2000, Harlen 2000). Finally, it conveys the sense of the historical development of science ideas, as a dialogue between scientists and nature, with answers leading necessarily to new questions, and a growing "approximation to truth" (Medawar 1984).

Thus, while a curriculum will necessarily make choices about the structure of the knowledge of a particular field, and the sequencing and cumulation of ideas, the curriculum as enacted must be consistent with the actual science that is being encountered, reducing the great distance between "school science" and "real science."

How does learning proceed? Research on minds and brains over the last century has consistently revealed that mastery of any kind of knowledge is a complex process, in which far more is involved than simple factual recall (Bransford et al. 2000). The educational community over the past century has articulated a rich idea of what outcomes are hoped for. For example, the National Science Standards envision students who are able to:

- experience the richness and excitement of knowing about and understanding the natural world;
- use appropriate scientific processes and principles in making personal decisions;
- engage intelligently in public discourse and debate about matters of scientific and technological concern; and increase

It has long been argued that humans most effectively learn in social settings in which an individual's understandings and assumptions are tested and refined in dialogue with peers and with experts

> their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers. (NRC 2000)

Such standards assume that the student will be good at the evaluation of evidence and the use of evidence in constructing an effective argument for or against a proposition or a course of action. The student will be able to recognize false reasoning, as well as counterfactual claims, and marshal and deploy her knowledge of fact and reasoning in a flexible manner which is exercised throughout her life.

Although this includes an understanding of science process (what Medawar calls the "hypothetico-deductive method,") (Medawar 1984) it also requires experience and skill at the negotiating of meaning. This means engaging in debate and discussion about science questions and the relevant data.

It has long been argued that humans most effectively learn in social settings in which an individual's understandings and assumptions are tested and refined in dialogue with peers and with experts (Dewey 1964, Vygotsky 1978). Thus the dialogue between the scientist and the natural world must be accompanied by a dialogue between the scientist and her colleagues. This is as true for the "student scientist" as for the practicing researcher.

How does a teacher facilitate the growth of science understanding? Given the assumption that the learner must actively construct his own knowledge, engaging both in a dialogue with nature (working with the phenomena) and in a dialogue with peers and experts, what does the teacher contribute? The teacher's expertise is fundamentally two-fold: on the one hand, she has an understanding of learning; on the other hand, she has a rich and flexible knowledge of her subject matter. This dual expertise becomes evident in the teacher's approach to the creation of a rigorous, question-rich science culture in the classroom, and also evident in the teacher's professional activities outside the classroom (Harlen 2000, Bransford 2000). It is important in reading this description of the inquiry-oriented teacher's approach that the classroom is not isolated and autonomous: while the teacher's skill and intent are basic requisites for the realization of an inquiry culture, as we describe here, the school and district cultures can play a powerful supporting or inhibiting role, and especially in the era of high-stakes testing.

• **Student understandings are at the core**. The inquiry-based classroom includes teacher inquiry into the students' actual understandings and mastery of the topics and methods addressed. The goal is the embedding of science information within a framework of cognitive and investigative skills, and within the framework of modern science and scientific history.

While lectures may be an essential ingredient, a primarily frontal teaching style cannot accommodate the range of activities that are necessary to students' gaining mastery of material.

Most pedagogical techniques can find their value in such a classroom, but the teacher needs to make sure that they are deployed in such a way that student questions, investigations, evidentiary arguments, and data analysis and presentation are at the core. While lectures may be an essential ingredient, a primarily frontal teaching style cannot accommodate the range of activities that are necessary to students' gaining mastery of material. Multiple classroom configurations and a variety of modes of student activity also provide a teacher with the richest and most timely information about the students' progress and problems (Driver et al. 2000, Falk and Drayton 2000b).

• **School science is not divorced from "real" science**. Science is practiced in a context of constant discovery, argument, and conjecture, within an explanatory framework or paradigm. This paradigm can both be seen as the state of current understanding, and also as a register of questions and directions for the creation of new knowledge. Teachers who seek to stimulate mastery in their students are able to show how the classroom's activities relate to lines of inquiry in the history of science (whether past investigations or current events). In this way, student meaning-making is situated within the enterprise of science outside the classroom (Harlen 2000, Driver et al. 1994).

Conceptual learning takes time for reflection, for cycles of experience and discussion, and often includes surprises.

• **Conceptual learning takes time**. Conceptual learning takes time for reflection, for cycles of experience and discussion, and often includes surprises. Teachers focused on successful student learning are therefore engaged in a battle to see to it that there is enough time for students both to make sense of their investigations, and carry through the core academic task of putting their learning into words and other forms that are communicable, relatable to the findings of the field, and amenable to critique and revision.

• **The teacher's interest in the content is infectious and inspiring** The teacher is the representative of science in the classroom. A science teacher conveys some critical information about science by his personal engagement with the material. Science thus comes across as both an important topic (for example, because of applications of scientific findings) and as a field for human enjoyment and creativity. The goal of a science-literate society rests on students' coming to see both reasons for staying engaged with science.

2. The inquiry-oriented classroom

What are key characteristics of the inquiry-oriented classroom which embodies the inquiry strategy? Before addressing this, it is worth noting that "inquiry" is a complex, a strategy with many possible tactics, and therefore the extent or quality of inquiry in a classroom may not be apparent in one observation. We suggest that three key questions can be very revealing of the state of inquiry in the classroom (Drayton and Falk 2001). These questions are:

1. Who is doing the intellectual work?
2. What purposes do hands-on activities serve?
3. What is valued by the students and the teacher?

1. Who is doing the intellectual work? Over the past century, almost everyone has learned in classrooms in which the teacher dominates the conversation in the classroom (Rothstein 1998, Sarason 1996, Cuban 1994). Studies of classroom discourse repeatedly show that in most classrooms it is the teacher who asks most of the questions. Unfortunately, these questions most often require short, "fill-in-the-blank" answers provided at significant pauses in a teacher discourse, rather than contributions revealing conceptual understanding. Thus in such classes it is the teacher who does the sense-making, provides the narrative, and tends to drive the class session on to a "successful" conclusion which may in fact have resulted in very little student learning at all (Drayton and Falk 2001b). In this sense, the teacher is the one who is doing the most important share of the intellectual work in the class, rather than the student. This is not to devalue the value of an effective teacher lecture or commentary, if it is used as part of an overall strategy aimed at supporting the students' active engagement with the substance of the classroom. In our work, the most effective inquiry-based classrooms include large stretches of student-to-student talk — problem-solving, investigation, discussion and argumentation about evidence, conclusions, and meanings.

2. What purposes do hands-on activities serve? Although many teachers see hands-on activities as key to the modern science classroom, and key to a definition of an inquiry approach (Falk and Drayton 2001b), we have found that it is important to examine the ways that these activities serve student sense-making and mastery, in order to understand the state of inquiry in the classroom. In our research in 40 Massachusetts middle-school classrooms, we have seen three broad types of hands-on activities (in prep).

a. **Activities that are used to convey content**. This is the rarest of the three types; yet it is the one that most closely approaches the goal of active student engagement in reasoning and investigation in science. In activities of this type, an investigation or challenge is the primary means through which curricular content is conveyed. For example, we observed an eighth-grade project

Studies of classroom discourse repeatedly show that in most classrooms it is the teacher who asks most of the questions.

in which teams of students investigated different aspects of a nearby ecosystem, each contributing a piece to the whole picture. This project provided both the need and the mechanism to learn about nutrient cycling, trophic levels, community ecology and environmental variables such as water quality, soil types, and dissolved oxygen — not only the topics, but the methods of measurement and research. Activities of this kind may include areas for significant student initiative or input, whether in the design of the question, the design or choice of method, or the analysis of data and interpretation of its significance. Such an activity is challenging to manage successfully, and can be costly in terms of time. Yet if it is not a regular feature of the classroom, the students cannot be expected to gain the kind of grasp of scientific reasoning, process, and results that our standards increasingly demand.

b. **Activities that engage attention, raise questions, or change pace**. Perhaps this is the commonest type of activity. While the core curricular content is conveyed in some other mode, such as teacher lecture or text, this kind of activity serves an important purpose. It can provide an introduction to a new topic area, or an opportunity to engage a phenomenon concretely, or a chance to learn an important investigative technique in practice and application. Such activities, which may focus on qualitative understanding, can be motivating, may raise questions or activate previous knowledge, or may help students understand something that other approaches have left opaque.

c. **Activities that primarily illustrate content**. In our research, we sometimes saw hands-on activities that seemed to provide little in the way of student cognitive activity. Sometimes this is because the activity itself has little content, for example, the creation of a geological timeline using a pre-fab format, and then recreating it using computer software. While this activity integrated the use of a software tool, it otherwise added no conceptual depth or increased investigative skill. More troubling are examples in which an activity is conducted in such a way that potential benefits are not realized. For example, in one classroom students placed cut-outs of dinosaur species on a map of the world. An effective use of this activity would have given familiarity with a prime data-set bearing on the theory of continental drift, as a prelude to an interpretation of this data, and its relation to other lines of evidence relevant to this major paradigm-shift in earth science. In this class, the evidentiary value of the dinosaurs' distribution was never addressed, and thus a potentially useful activity was reduced to a simple exercise with scissors and glue.

All three types of hands-on activities may coexist in a teacher's practice. In implementing an inquiry strategy, however, it is worth examining the relative proportions in which they occur, and whether some types, such as (a), are present at all. The quality of the activities should be evaluated in the light of the previous question, Who is doing the intellectual work? It can be valuable to ask questions such as these: In this activity, who is choosing the question to investigate, the teacher or the student? Who is choosing the method? Who is doing the analysis, and proposing the solution? Such an evaluation relates naturally as well to our next question, which is about the building of shared values and markers of quality in the science classroom.

3. What is valued by the students and by the teacher? What represents success in the classroom? Does the teacher help create a climate of sense-making, critical reasoning, and clear articulation of concepts and processes? If classroom work (including reading, group work, projects, teacher talk, and other elements) is always placed in the context of a growing control of good science process, including data collection, analysis, interpretation, and presentation, this then sets norms which feed directly into student and teacher assessments of student learning. Students should understand what the goals are for the current curriculum unit, and understand the teachers' criteria for quality. These criteria should be rooted in careful science process, effective reasoning and use of evidence, and skills of interpretation and presentation of qualitative as well as quantitative results. Thus the classroom activities are tied to rubrics for success, in such a way as to be mutually supportive (NRC 2000, Harlen 2000, Falk 1993).

3. Features of a school that is hospitable to inquiry

School culture can either support or hinder the development and survival of a classroom of the sort described above. The teacher has some autonomy "once the classroom door closes," but less than is sometimes thought (Falk and Drayton 2000b; Sarason 1996). We have seen how even experienced inquiry-oriented teachers are less likely to scaffold rich investigations, or spend time on rigorous qualitative and quantitative reasoning, if the school climate is not favorable. In an unfavorable climate, new teachers, or teachers new to an inquiry orientation, can be prevented from the reflective practice and experimentation that is required to become comfortable and flexible inquiry-oriented teachers. What are key features of a favorable climate? Our observations suggest the following 5 points, which are supported by many studies of the effects of the school on other classroom innovations:

a. **Flexibility in scheduling is an essential nutrient.** We have seen that another critical resource for teachers is time. This, too, seems a truism (Hargreaves 1994), but it has particular bearing on inquiry-oriented science. If there is not some opportunity for extended class periods (whether through flexible scheduling or the availability of block periods), certain important classroom activities are very difficult to implement, for example data collection that is unpredictable in duration (as in taking water or air quality samples). Natural phenomena, and reasoning about them, do not always fit well into 45-minute class periods, and the more they are incorporated into the classroom, the more important a flexible schedule becomes.

A school's deployment of resources can either support or hinder the development of an inquiry-oriented classroom.

If the teacher is to understand science practice, and support its growth in his students, he must experience science first-hand.

b. **Good curriculum materials help support the growth of inquiry**. A school's deployment of resources can either support or hinder the development of an inquiry-oriented classroom. It is obvious that flexible, adequate curriculum materials are important, and the best of these will not only provide the teacher with specific, concrete guidance for classroom activities, but will also support the teacher's growth of skill in supporting student thinking and mastery.

c. **Schools should support connections between the classroom and science outside the classroom.** Since the inquiry-oriented classroom seeks to engage students with the activity of science, as well as its findings, the students need contact with working scientists in their community, and (in age-appropriate forms) see science being practiced. The frequently-seen visit of a scientist to the classroom should be supplemented by site visits, collaborations with scientists on classroom or extra-curricular investigations, and (for older students) shadowing opportunities or internships.

d. **Professional development should include teacher experience with science research.** Too often, professional development for science teachers begins and ends with the learning of new curriculum units. If the teacher is to understand science practice, and support its growth in his students, he must experience science first-hand. Teachers should be supported in making connections with scientists in their area, following up on their own interests, and when possible taking part in science research of some kind. This experience lends a level of authenticity and confidence to the teacher as the representative of science in the classroom, and goes an important distance towards eliminating the stultifying distance between "school science" and "real science" (Drayton and Falk 2000; Falk and Drayton 1998, 1997).

e. **The school should foster a climate of collegial exchange, and dedicated time for it to happen**. In our work, we have found that the single most effective change that many schools could make to support the implementation of inquiry-based science is to support substantive talk among the science teachers about curricular content and pedagogical

Teachers learn just as students do, through experiment, reasoning about data, and discussion with peers who are exploring similar questions and challenges.

approaches to it. Teachers learn just as students do, through experiment, reasoning about data, and discussion with peers who are exploring similar questions and challenges (Huberman 1993). With the dizzying changes in the field of science, the burgeoning of curriculum materials and other resources, and the implementation of new standards and other state mandates, teachers more than ever need an opportunity to discuss, evaluate, and plan with their colleagues. Such conversations should focus both on science content, and about student understandings and student work. This kind of collegial exchange creates a culture of continuous improvement, but cannot do so if it is a rare event, or random moments snatched from time to time. It is a core resource for a strong science program (Falk and Drayton 2001b, 2000b).

4. Features of a district that is hospitable to inquiry

An inquiry-oriented school requires a favorable district climate. Increasingly, the focus on the systemic nature of schooling has produced research showing the powerful effects that the school district can have in setting expectations, and fostering or hindering the realization of a strong science program (Falk and Drayton 2001b, Spillane and Callaghan 2000, Raizen and Britten 1997). Of course, district policy can be modulated by school policy, but we suggest that the following are areas in which the district is especially important.

a. **Coordinate innovations around a clear pedagogical vision**. It is sobering to make a list of the range of innovations, reforms, or policy mandates that are being implemented in any district in the country. From drug-education policy to the use of technology to the implementation of inquiry-based science — the many mandates come from many sources, and thus there is a real danger that they will not be implemented with any pedagogical strategy to coordinate them. In light of the specific needs we have mentioned for resources, for professional development, and for patterns of collegial exchange, there is a real danger that inquiry-based science can be inadvertently hindered by other good reforms in one way or another (Drayton and Falk 2001b, Falk and Drayton 2000b, Knapp et al. 1998). Therefore, the district can play an important role in the establishment of inquiry-based science, by articulating and advocating a pedagogical vision consonant with the development of a culture of inquiry.

b. **Buffer the schools and teachers against the negative effects of high-stakes testing**. A vision for inquiry can be derailed by competing pressures for high scores on state-mandated tests. The advent of the standards movement, followed in most states by mandatory testing, has brought new pressures to bear on the classroom, and often takes the form of pressure for more coverage of material, and undue time spent on test-preparation. We have found that a district that

We have found that a district that has developed a clear vision of inquiry-based science, and has embedded its pedagogy, assessment, and curriculum, can counteract many of the negative effects of high-stakes testing.

has developed a clear vision of inquiry-based science, and has embedded it in pedagogy, assessment, and curriculum, can counteract many of the negative effects of high-stakes testing (Falk and Drayton 2001a). By contrast, teachers in districts that have not developed and implemented such a vision are much more vulnerable to pressure to surrender their pedagogy to test-preparation, with negative effects that have been ascertained widely (Falk and Drayton 2001a, Heubert and Hauser 1999).

c. **Support the development of teacher learning and pedagogical talk**. Many districts coordinate professional development for their teachers; many districts also develop detailed science curriculum guidelines, and often coordinate the purchase of materials with their curriculum. Therefore, the district has an opportunity to provide leadership in the development of opportunities for between-school or cross-district collegial exchange among the science teachers, of the sort discussed above for the faculty of a particular school. Districts where inquiry is deeply embedded in the culture have created structures for cross-school dialogue. These structures reinforce the pedagogical vision of the district, as well as engaging the teachers in informed evaluation of the content of that vision, and the curriculum that is used to implement it (Falk and Drayton 2000).

The inquiry-based strategy for science education is a complex one, and requires much care and clarity of vision at every level, from district to classroom.

In summary

The inquiry-based strategy for science education is a complex one, and requires much care and clarity of vision at every level, from district to classroom. Yet this complexity arises from the nature of the subject matter itself, and the standards for good science learning which have been developed with increasing clarity in the past decade. Therefore, an inquiry-based program is most closely matched to the imperatives of its subject matter, being calculated to enable the learner to think critically while continuing to learn, and to motivate the learner to continue learning, by scaffolded participation in the core of science — asking questions of nature, and building the remarkable and dynamic edifice of explanation and conjecture that is science.

This cumulative, strategic growth of reasoning power and scientific understanding makes important demands on teachers, schools, and districts. These demands, for good materials but even more for teacher learning and collegial talk, appropriate deployment of materials and time, and consistent pedagogical vision from the district level on down, follow from the very nature of the subject matter of modern science, and from our best understanding of learning and teaching. Thus, science education is doubly systemic: it takes place in the layered system of the classroom, school, and district, and also takes its place in the web of organized wonder and investigation that is the scientific enterprise.

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Footnotes

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Richard A. Huber, Christopher J. Moore

High Stakes Testing and Science Learning Assessment

An argument is made for the use of interactive computer application as a vehicle for incorporating more authentic assessments of students' learning of inquiry into standardized testing.

In a recent publication (Huber and Moore, 2000) we argued that science education supervisors would be well advised to work towards ensuring that well meaning but misguided efforts to promote educational reform through standardized testing do not undermine true "standards-based" reforms—that is, reforms consistent with those envisioned in *the National Science Education Standards* (National Research Council, 1996). In that article we discussed how the *Standards* foresaw the potential for problems arising out of poorly conceived implementations of standardized testing and warned the education community about them—and provided guidance on how to prevent or mitigate some of the potential damages poorly conceived testing programs might cause. Among the guidance provided in the *Standards* are admonitions to science education supervisors to champion the cause for the use of appropriate and valid assessment tools. (For the purposes of this discussion, appropriate tools are defined as those that purport to measure the achievement of learning objectives congruent with the *Standards*; valid tools are those that do measure what they purport to measure). In this paper, we provide a follow-up to our previous discussion on the threat of high stakes testing with recommendations on how science education supervisors might mitigate the negative impact of high stakes accountability testing by championing the cause for the development and use of more appropriate and valid assessment tools. Specifically, this paper discusses the possibly beneficial roles of new interactive Internet technologies as tools for assessing inquiry-based science learning.

Standardized tests within high stakes testing programs clearly act as a dominant force in the current streams of thought and politic shaping American K-12 education.

Standardized tests within high stakes testing programs clearly act as a dominant force in the current streams of thought and politic shaping American K-12 education. In our previous article, we described how accountability testing was a strong and growing force, noting President Clinton's endorsement of accountability testing as an indication of the breadth of support for the testing. Since that time, emphasis on using standardized tests in accountability testing has increased, and the federal support for testing of "all students at all grades" has increased under the Bush administration. Clearly, high stakes accountability testing is not a passing fad.

It is equally clear that many of the changes wrought by testing-based reform initiatives are antithetical to the goals of the *Standards*. To a substantial degree, standardized testing is growing as a driving force in establishing curriculum goals and methods of instruction (Brady, 2000; Brandt, 1989; CNN, 1999; Jones et al., 1999; Huber and Moore, 2000; Kohn, 2001; Kunen, 1997; Merrow, 2001; Neill, 1998; Shapiro, 1998). As aptly stated in one popular press publication, high stakes accountability testing has become, "the latest silver bullet designed to cure all that ails public education" (Kunen, 1997, p. 24). Others have more strongly condemned current accountability testing practices. Kohn (2001), for example, refers to standardized

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testing as a "monster" which makes it "… difficult, perhaps even impossible, to pursue the kinds of reforms that can truly improve teaching and learning" (p. 350).

The central problem with current use of standardized tests within accountability testing is two fold. First, as noted above, the tests play a strong part in shaping curriculum. Secondly the tests typically assess the wrong "stuff." Tests typically emphasize the wrong content because all too often that which is easy to assess is not that which is important to learn, especially in the sciences. Standardized testing typically emphasizes the memorization of objective facts learned in isolation through practices favoring "superficial" levels of student engagement rather than the development of richly structured knowledge and upper-level thinking skills learned through pedagogues requiring more active engagement on the part of the student (Huber and Moore, 2000; Jones et al., 1999, Kohn, 2001; Livingston et al., 1989; Madaus, 1991; Merrow, 2001; National Research Council, 1996; Neill, 1998; Neill and Medina, 1989). Thus, in the absence of more authentic assessment strategies than those typically employed in standardized testing, the contemporary wave of political support for educational reform through accountability testing can be expected to push science education practices away from inquiry-based instruction as envisioned in the *Standards* (Huber and Moore, 2000).

Strong concerns also have been raised about bias in standardized tests, which would unquestionably cause the tests to work against the *Standards'* goals of equity in science education (CNN, 1999; Darling-Hammond, 1991; Kohn, 2001; Neill, 1998; Neill and Medina, 1989). Additionally, there is strong evidence that accountability testing places undue and detrimental pressures on teachers and students. Pressures to "teach to the test" experienced by teachers work against the Standards' goals of changing the roles of teachers from those of teachers as followers and technicians to roles of teachers as creative leaders and contributing stakeholders in reform initiatives (Huber and Moore, 2000; Jones et al., 1999; Haladyna et al., 1991; Smith, 1991). In a similar manner, testing pressure on teachers and students alike work against *Standards'* goals focused on affective domain learning, such as promotion of students' love of learning, students' willingness to take risks in learning, and students' taking ownership of their learning (Huber and Moore, 2000; Hill and Wingfield, 1984; Jones et al., 1999; Kohn, 2001; Merrow, 2001; Shapiro, 1998).

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The *Standards* predicted how high stakes accountability testing protocols, as currently implemented, would work against the goals of *Standards*-based reforms. First, the *Standards* correctly point out that testing protocols that arise out of political agendas are apt to be too short sighted to be effective in establishing or furthering the types of substantial reforms called for in the *Standards*. The *Standards* state,

> New administrations often make radical changes in policy and initiatives and this practice is detrimental to education change, which takes longer than the typical 2- or 4- year term of elected office. Changes that will bring contemporary science education practices to the level of quality specified in the *Standards* will require a sustained effort" (National Research Council, 1996, p. 231-232).

Secondly, the criteria stated in Assessment Standards A through E within the *National Science Education Standards* effectively head off most current testing-based reform initiatives at the pass (National Research Council, 1996, p. 78-86). These standards call for assessments strategies and tools that are well-thought out, deliberate in design, and consistent with the decisions they are designed to inform

(Standard A). The assessments must measure opportunity to learn (Standard B), and they must be valid (Standard C), fair (Standard D), and sound (Standard E). As the review of literature on standardized testing above suggests, there is good reason to doubt that current implementations of standardized testing meet these criteria.

For the purposes of this discussion, Assessment Standard C is particularly relevant. This Standard states, "The technical quality of the data collected is well matched to the decision and actions taken on the basis of their interpretation." An explicitly stated sub-requirement of this standard is that, "Assessment tasks are authentic." In elaborating on this standard, the *Standards* specifically point out the importance of assessing students' abilities to conduct inquiries and point out that multiple-choice question formats—as are typically used on standardized tests—lack validity and are "inappropriate" for assessing student learning of inquiry skills. Thus a different kind of standardized test item is warranted for assessing inquiry learning.

Importantly, the *Standards* place at least part of the responsibility for promoting the development and implementation of authentic assessment tools on science education supervisors at the district level of administration (see, for example, National Research Council, 1996, p. 240). The *Standards* take this position in recognition of the fact that assessment often drives instruction and, therefore, assessment practices must be changed if teaching practices are to change (National Research Council, 1996, especially pages 75-78). Toward this end, interactive computer applications have been recognized as a possible means of incorporating more authentic assessments of students' learning of inquiry into standardized testing (Moore and Huber, in press).

An examination of science education resources available on the Internet suggests that interactive computer-based science applications may provide a useful means of assessing students learning of inquiry-based science content.

An examination of science education resources available on the Internet suggests that interactive computer-based science applications may provide a useful means of assessing students learning of inquiry-based science content. In a paper on interactive inquiry-based Internet activities (Moore and Huber, in press) we describe an example of how an interactive computer application, based upon an existing Internet application, could be used to assess student learning of concepts related to density and the science process skills involved in students' inquiry-based learning of those concepts (see "Density Lab" at http://ExploreScience.com). If such assessments were used, and if the assessments influenced teaching decisions as expected, the use of such assessments could be expected to encourage teachers to use an inquiry-based approach. In fact, it is difficult to imagine how students could perform well on the assessment unless they were taught about density through an inquiry-based approach.

As currently implemented, the density exploration Internet application allows students to work with items displayed on the computer screen, clicking and dragging displays of irregular objects onto displayed balances (to measure their masses) and into displayed graduated cylinders (to measure their volumes) in order to obtain the information needed to calculate their densities. We proposed that, with only minor changes, the computer program could be altered into an assessment tool that could be used to measure how well students understood the concept of density and how well they were able to measure the density of various objects, using balances and graduated cylinders. Because the computer could track the steps students performed in completing assigned tasks, scores could be based upon effective use of science process and laboratory manipulative skills, rather than merely selecting the best answer from four or five multiple choice options.

At this time there are numerous inquiry-based interactive Internet applications that, like the density lab example above, are designed to facilitate students in conducting inquiries, using simulated scientific equipment and/or research settings. Many of these applications might be readily modified to create reasonably authentic, highly valid, inquiry-based assessment tools. A few examples of the types of assessment items that might be developed from existing Internet resources are as follows:

- Inquiry learning of Newton's laws of motion could be assessed using variations of a number of applets found at Explore Science.com (http://ExploreScience.com) including "2D Collisions," "Air Track," "Golf Range," "Inclined Plane," and "Shoot the Monkey."

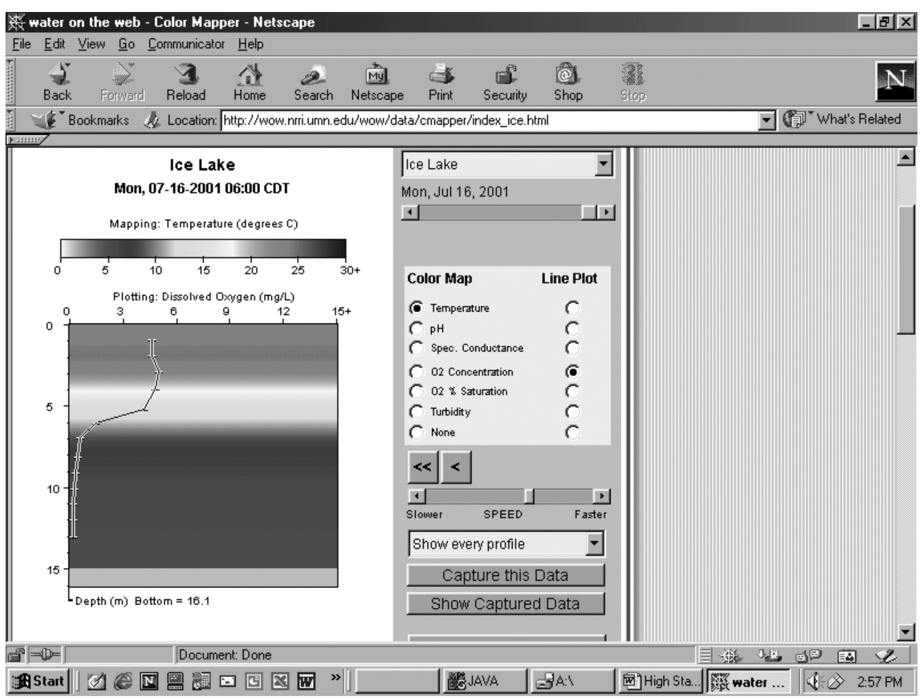
- Inquiry learning of the physics of sound could be assessed using modifications of applets found at (1) "Soundary," an application in the ThinkQuest library of interactive science education applications (http://www.thinkquest.org/library/index.html) and (2) "Doppler Effect," and "Interference Patterns," included within the ExploreScience.com web site.
- Inquiry learning of the physics of light could be assessed using variations of a number of applets also found at Explore Science.com including "Additive Colors," "Subtractive Colors," and "Basic Prism."
- Inquiry learning of genetics could be assessed using applets similar to those found at (1) "Mouse Genetics" at Explore Science.com and (2) "Engineer a Crop" at Nova Hot Science (http://www.pbs.org/wgbh/nova/hotscience/).

Another kind of interactive inquiry-based Internet application provides students with access to large data sets and powerful data manipulation tools for exploring the data and testing hypothesis using that data (Huber and Moore, 2001b; Moore and Huber, in press). Examples of this type of site include "water on the web" (http://wow.nrri.umn.edu/wow/index.html) and "river run" (http://www.uncwil.edu/riverrun). Assessment tools based on these application could be used to assess a variety of inquiry-based learning, including knowledge and abilities in the areas of environmental sciences; skills in the use of computer technology to pose and test a hypothesis; and the use of multivariant graphs for interpreting, displaying, and explaining scientific data.

Water on the Web (WOW) provides water quality data collected from remote underwater sampling stations placed in five Minnesota lakes, which continuously sample and analyze water from different depths in the lakes. "Data Visualization Tools," accessible from the WOW web site, allows students to see and explore relationships among the data points that would probably be lost to them were the data merely displayed as matrixes of numbers. Importantly, students can, with a few points and clicks, change parameters that define the dynamic graphic displays. Thus, the utilities provide simple and engaging mediums for open exploration and powerful effective tools for hypothesis testing. For example, in an inquiry-based classroom a teacher might direct students to use the "color mapper" data visualization tool to explore lake stratification. Under this scenario, the teacher might have students define the parameters so that water temperature is color-graphed and dissolved oxygen is shown with a line graph, as shown in Figure 1 (note that different students could be looking at data from various lakes and at various time frames in this example). Through the teacher-guided inquiry, students should quickly discover how sharp gradients in temperature and dissolved oxygen define the epilimnion strata at the surface of lakes. Students could then predict how other variables might behave around this boundary and, ultimately, change system settings, and "run" animations to test their hypotheses.

Data visualization tools within WOW are also well suited for present-

Figure 1. Example of a Data Visualization Tool presentation of Ice Lake in Northern Minnesota from Water on the Web.



ing clear pictures of various complex and interesting phenomena and events that occur within lake ecosystems. For example because water is at its densest at 4˚C, in a deep lake the water at the bottom of the lake remains at 4˚C year-round. Consequently, as surface waters cool to this temperature in the autumn and warm in the spring, the waters of a deep lake can dynamically "turn over." The color mapper tool is an ideal resource for exploring and displaying the impacts of this dynamic event.

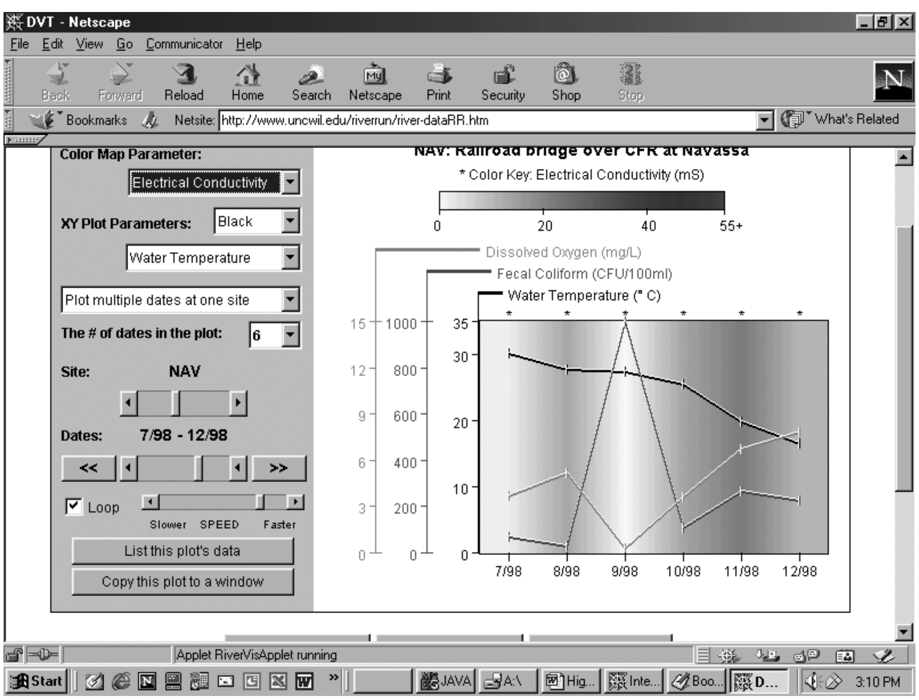
River Run offers two main interactive data displays, the Geographic Information Service (GIS) and the Data Visualization Tool (DVT). GIS is a computer utility for mapping and analyzing geographic locations and numerical data of events that occurred at those places. This tool gives the user the power to link databases and maps to create dynamic displays. The Data Visualization Tool is similar to the color mapper for lake data described above, with the exception that the X-axis of the displayed graphs is analogous to the Y-axis in the lake data. That is, in the lake graphs the vertical dimension is used to map lake depth, whereas in the river graphs, the horizontal axis of the graph maps the flow of the river (from upstream on the left to downstream on the right).

A strength of both of these applications is that they are well equipped to facilitate student inquiries involving extensive hypothesis formation and testing (Huber and Moore, 2001b; Moore and Huber, In press). For example, Huber and Moore (2001b) describe how the River Run data visualization tool can be used to invite students into inquiries about the impacts of hurricanes on river systems.

In their example, students are directed to explore the database using the animated graphic displays and try to find "anomalies" or sudden dramatic changes in the data displays. Students might discover the frame shown in Figure 2, which shows, among other things, a dramatic spike in fecal coliform bacteria and a drop in dissolved oxygen. Through guided explorations of the River Run data base and other sources of information (which are available online), students can "discover" that these events were caused by the hurricane-induced failure of a sewage treatment plant.

In their example, students are directed to explore the database using the animated graphic displays and try to find "anomalies" or sudden dramatic changes in the data displays.

Figure 2. Example of a Data Visualization Tool presentation of four water parameters during Hurricane Bonnie from the River Run web site.



It is not an unreasonable expectation that utilities such as River Run and WOW could be expanded to incorporate online assessments of students' performance in forming and testing hypotheses, such as those discussed above using the data and data visualization tools within the utilities. These assessment tools would be completely authentic; they would assess students' use of real scientific tools (computer utilities designed to support scientific explorations of large data sets), using authentic higher-order thinking science process skills (interpreting graphs, predicting and inferring, and hypothesis testing). Further, as proposed for the assessment item on measuring density, the computer could track students' steps in exploring the data base and therefore assess the

The Standards are unambiguous in their call for science education supervisors to step into the fray of educational reforms.

process of students' inquiries, as well as the outcome of the inquiries.

In conclusion, standardized accountability testing, as currently implemented, works against more substantial and meaningful reform initiatives, such as those envisioned in the *National Science Education Standards*. The *Standards* are unambiguous in their call for science education supervisors to step into the fray of educational reforms. As part of that calling, the *Standards* ask science education supervisors to step up to the plate in efforts to develop and implement authentic assessment tools. Interactive computer applications, such as those employed in K-12 science education applications currently available on the Internet, appear to represent an as of yet largely untapped gold mine of resources for developing authentic inquiry-learning assessment items. We urge science supervisors to promote the development and implementation of assessment tools congruent with those Internet applications.

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Lynn T. Goldsmith, Marian M. Pasquale

Providing School and District-level Support for Science Education Reform

Administrators who are viewed as knowledgeable about the issues and challenges involved in developing scientifically literate students are in a stronger position to promote and facilitate improvements in the science curriculum as well as its implementation.

In this age driven largely by scientific and technological advances we put a premium on rigorous scientific training for our students, and yet our science education currently fails to meet the grade. Data about the effectiveness of U.S. science education has been clear, and discouraging, for over a decade now: our nation's students are not the scientific thinkers and problem solvers they should be. Reports of U.S. students' performance on both the Third International Mathematics and Science Study (TIMSS) and the National Assessment of Educational Progress (NAEP) echo a dismal message of lackluster performance (Dossey, Mullis, & Jones, 1993; Schmidt, McKnight, & Raizen, 1997). Students fail to demonstrate the skill mastery, depth of knowledge, or ability to inquire and investigate that characterize scientifically proficient students. We are not yet doing the job that we should (or can) do to teach our children to understand and use ideas from science (National Commission on Mathematics and Science Teaching for the 21st Century, 2000).

In large measure, this failure is due to chronically low expectations for our students and approaches to curriculum and instruction that fail to build active and independent scientific thinkers (Stevenson & Stigler, 1993; Stigler & Hiebert, 1999). For example, the typical science curriculum, often described as "a mile wide and an inch deep," fails to provide students with opportunities to engage in authentic scientific thinking. Across the nation, the emphasis has consistently favored the quantity of information presented to students rather than the quality of students' understanding (Rutherford & Ahlgren, 1990). Teachers spend a significant amount of instructional time reviewing and re-teaching topics from previous years rather than deepening and extending students' understanding. Students spend much of their time memorizing definitions of scientific phenomena and labels for scientific processes rather than learning to engage in disciplined inquiry of important scientific ideas. Their ability to think scientifically is compromised by a focus on the "what?" of science rather than on the "how?" or "why?" (National Commission on Mathematics and Science Teaching for the 21st Century, 2000). If we are to improve students' science achievement, we must change both the content that students learn and the way that they learn it. We need to give students the chance to study a coherent and challenging curriculum that emphasizes conceptual understanding, problem solving capability, and effective communication of scientific ideas. We must also help students develop "higher order" thinking skills by teaching them to make systematic observations, develop hypotheses, design and conduct investigations, and reason from data.

We need to give students the chance to study a coherent and challenging curriculum that emphasizes conceptual understanding, problem solving capability, and effective communication of scientific ideas.

Reforming science education in these ways will involve making changes throughout the system. Schools and

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districts will need to identify clear goals for high student achievement, and to apply these goals to *all* students (Mitchell & Willis, 1995; National Research Council [NRC], 1996). They must plan a challenging curriculum to meet these goals, adopting materials that are both academically rigorous and instructionally effective with a wide range of students (Berns et al., 2001; Goldsmith & Kantrov, 2000; Schmidt, McKnight, & Raizen, 1997). In addition, teachers must participate in high-quality professional development to ensure that they are well prepared to teach a more intellectually demanding curriculum and to call upon a repertoire of instructional approaches to engage students as active scientific thinkers and problem solvers (Rhoton & Bowers, 2001).

How can principals and other district administrators help promote such changes? As instructional leaders, there are three important ways that administrators can make a difference in science education. First, they can make sure they are prepared to lead by learning about the goals and approaches of science education reform, and about the resources needed to improve science education in their schools. Second, they can lead and support specific school improvement efforts within the district. Finally, they can help involve parents and other community members in efforts to improve science education.

Learn About Science Education Reform

Administrators who are knowledgeable about the issues and challenges involved in developing scientifically literate students will be in a stronger position to promote and facilitate improvements in the science curriculum itself and in its implementation. We describe a number of ways to learn about the goals and approaches of science education reform in this section.

Do some research. There is no shortage of written material devoted to the topic of science education reform. Learn about the standards that are driving the current reform movement by reading some of the many policy documents, books, articles, and even web-hosted discussions concerning science standards and their implementation. When administrators have a deep understanding of the goals and underlying philosophy driving the standards, they will be able to make better informed decisions about promoting rigorous science education at the local level.

Two important documents are the *National Science Education Standards* (1996), published by the National Research Council (NRC) and *Benchmarks for Science Literacy* (1993), written by the American Association for the Advancement of Science (AAAS). They articulate a rationale for new approaches to science teaching and learning, lay out expectations for science literacy, recommend curriculum content, and describe approaches to instruction and assessment that are consistent with reform philosophy and goals. Both documents have been widely used by states and districts as the foundation for developing their own frameworks and performance standards.

The National Association of Science Teachers (NSTA) publishes two monthly journals devoted to science teaching in middle and high schools, *Science Scope* and *Science Teacher.* Project 2061 of the AAAS also publishes relevant materials, including a variety of books and reports about science education and *2061 Today,* a biannual newsletter featuring discussions of current issues in science education. Other educational publications also carry articles about science, and some occasionally devote special issues to the subject (e.g., National Association of Secondary School Principals, 2001). Finally, there is the Internet, which is rapidly expanding as a bibliographic resource. Good web sites to consult when starting a search about science education literature include the U.S. Department of Education, the Eisenhower National Clearinghouse for Mathematics and Science Education (ENC), the K-12 Science Curriculum Dissemination Center at Education Development Center, Inc. and the SCI Center at Biological Sciences Curriculum Study (BSCS). Web sites of organizations cited in this paper are listed at the end of this article.

Do some science. Firsthand experience with science investigations is one of the best ways to get a sense of the kind of reasoning and problem solving that lies at the heart of science education reform. Try your hand at activities like the one in Figure 1.

Figure 1

Standards-based Science Activity

The following activity calls upon students to apply science concepts and skills to the solution of a practical problem. In order to meet the challenge, students must use their understanding of energy transfer and the structure and properties of matter. Their inquiry skills are also called into play in the design and testing of their work.

Chapter Challenge

You are a member of a team of engineers who is developing a communications system. The system must communicate from one room to the next. Since the system is a model for long-distance communication, assume that the other room is far away. Yelling and waving will not work. The requirement is that you are able to send and receive a message. You will have to divide your team into senders and receivers, with the receivers in the other room. You will have about five minutes to set up your system before you test it to meet the requirement. During the test, you must measure the speed of transmission of your system.
In this test, the message you will communicate will be simple and brief and may include either text, picture, music or a combination of these.

Excerpted from Active Physics/Communication © 2000. Used with permission of It's About Time Inc.

Activities like this "communications system challenge" are challenging, engaging, conceptually rich, and also accessible to students with a range of "learning styles."

As Figure 1 points out, there are several ways to develop an effective solution to a challenge. Science educators emphasize the value in approaching a single problem with a number of strategies. Taking various approaches to a problem often reveals different aspects of the science and understanding different approaches also helps students make strong connections among science concepts. Sharing ideas can also stimulate thinking and raise other questions to investigate. This, too, is a feature of today's science teaching.

Professional development is key to science education reform: administrators and teachers alike need time to study and explore the shifts in perspectives on science learning and teaching that underlie the reform effort.

Seek professional development opportunities. Professional development is key to science education reform: administrators and teachers alike need time to study and explore the shifts in perspectives on science learning and teaching that underlie the reform effort. Therefore, it is important for principals and district-level science staff to work with the central administration to provide professional development opportunities geared specifically toward district leadership. For example, administrators can encourage the district science coordinator to offer "science inquiry labs" where administrators can explore science questions for themselves. Principals can also request that the district support study groups and workshops focusing on those aspects of science education reform that are of particular importance to district and building leaders, for example, using data about student performance to design school improvement plans or developing new approaches to teacher supervision (Nelson & Sassi, 1998). Principals can also participate in professional development activities as part of a school team. Working side by side with teachers offers an opportunity to learn close up about new approaches to science education and provides a chance to learn about the challenges teachers encounter in implementing reform-based curriculum and instruction.

Attend conferences, make contacts. Another way to learn about science education reform is by attending meetings and conferences. The National Science Teachers' Association (NSTA) holds regional and national meetings each year. There are also meetings for specific science disciplines. The National Association of Biology Teachers and the American Association of Physics Teachers each hold their own conferences and publish materials relating to the teaching of their particular disciplines. The American Chemical Society includes a division of Chemistry Education which focuses on high school and college chemistry instruction. Because such professional meetings convene a large number of educators concerned about science education, they can be an efficient way to tap a number of different kinds of resources. There are opportunities to listen to speakers discuss current trends and practices in science education, to review curriculum materials and other resources, and to meet other educators committed to improving science teaching and learning in their schools.

Networking within your own circle of colleagues is another effective way to learn about the benefits and challenges to reforming science education. Speak with colleagues who are working to boost science achievement in their schools and visit classrooms where teachers are using new curriculum materials and instructional approaches to see what standards-based instruction looks like (Clark & Clark, 2000; Elmore & Burney, 1999).

Support School Improvement Efforts

Principals, curriculum coordinators, and science specialists can play significant roles as instructional leaders in science education by setting the tone for educational excellence, establishing school structures to support high achievement, and finding the resources needed to translate that commitment into action. There are a number of ways to do this.

Support faculty professional development. Implicit in the call for a different kind of science learning is a different kind of teaching. Teachers are being asked to make their instruction more interactive and inquiry-based, and to focus more on reasoning, problem solving, and discussion. They are also being asked to use their own scientific knowledge and understanding in new ways. The shifts in recommended curriculum content (NRC 1995, 1996), paired with the greater focus on conceptual understanding and non-routine investigations, means that teachers need a deeper and more elaborated understanding of the science they teach. Many teachers need time, support, and practice to deepen their content knowledge and develop new instructional approaches (Rhoton & Bowers, 2001; Thompson & Zeuli, 1999).

Many teachers need time, support, and practice to deepen their content knowledge and develop new instructional approaches.

Administrators can contribute significantly to improving science teaching by identifying the professional development needs of the faculty, and then helping teachers meet these needs. The kind of professional development needed to support standards-based instruction is far different from the familiar "make it and take it" workshops of the past. Professional development is most effective when it is ongoing, focused on deepening both scientific and pedagogical understanding, grounded in teachers' practice, and tied to district goals and standards (Ball & Cohen, 1999; Rhoton, 2001; Thompson & Zeuli, 1999).

"Off-site" programs such as summer institutes or yearlong courses offered by experienced teacher educators combine intensive study of science and of pedagogical approaches that promote student engagement with important scientific concepts. This type of professional development also offers opportunities for teachers to develop collegial relationships that center around the study of science instruction. The Eisenhower National Clearinghouse (ENC) web site, *The Annenberg/CPB Guide to Math and Science Reform* (available on the Annenberg/CPB web site), and the NSTA are good resources for initial investigations of off-site opportunities.

Institutes and courses can help create awareness of the need for changes in curriculum and practice, and can help teachers and administrators get started on the journey toward change. However, it is primarily the work that teachers do together within their schools and the district as a whole that builds and sustains reform efforts. Administrators can reinforce teachers' off-site experiences by making sure that their schools create the expectation that faculty and staff will invest time, thought, and energy in their efforts to improve students' scientific understanding, and then develop structures to support their efforts. These structures may include common preparation times, teacher study groups, meetings devoted to analyzing student work, coaching and mentoring programs, and provisions to visit colleagues' classrooms. The emphasis on collaboration, investigation, and reflection helps establish a culture of professional inquiry within the school that promotes excellence in both teaching and learning (Drayton & Falk, 2001; Elmore & Burney, 1999; Little, 1999; see also Loucks-

A guiding principle of science education reform is that all students will have access to a coherent and challenging course of study in science.

Horsely, Hewson, Love, & Stiles, 1998 for discussion of different models of professional development).

Support a challenging curriculum for all students. A guiding principle of science education reform is that all students will have access to a coherent and challenging course of study in science. The science curriculum should develop deep understanding of science concepts, promote inquiry, emphasize reasoning and argument, develop communication skills, and introduce science concepts and thinking from kindergarten through high school (NRC, 1995; Raloff, 2001; Rutherford & Ahlgren, 1990; Schmidt, 2001).

Comprehensive science curriculum programs, supplementary materials, and related technologies can help to promote these curricular goals. When district curriculum selection committees meet to adopt new materials, encourage members to look to research on best instructional practices and data about student achievement when making decisions. Recommend as well that members consult curriculum evaluations based on standards-based criteria (Project 2061, 1999; U.S. Department of Education, 2001). Recognize, too, that curriculum decisions should take into account factors in addition to the science content of the program. The developmental appropriateness of the materials and the ways they will promote learning for all students, the kinds of resources the district will need to adequately support implementation, the needs and concerns of the larger community, and the policies and practices of the district are among the factors that should also influence decision making (Berns et al., 2001; Goldsmith & Kantrov, 2000).

Commit resources. Committing resources for ongoing staff professional development is extremely important. Title I funds and Title II (Eisenhower) grants can help support such activities. (Restrictions on use of Title I funds have recently been eased.) Districts can also apply to the National Science Foundation for systemic initiative grants and to the U.S. Department of Education programs to support school reform (information is available on the NSF and U.S. Department of Education web sites). Some of these funds can be used to support professional development programs within the school and to send teachers to off-site programs, too. Make sure that part of your plan for using resources involves mechanisms for coordinating and monitoring your improvement efforts (Bond, Boyd, & Montgomery, 1999).

Another way to support teachers is to arrange for release time to permit attendance at professional development programs or conferences, or for visits to other classrooms. This may mean helping to find competent substitutes as well as paying for them. Some schools have developed relationships with businesses in their communities that allow company employees to volunteer to teach classes, often on a regular basis (Education Development Center, 1994). Principals can also support teachers' professional development by arranging teaching schedules to create common preparation times, committing some departmental meeting times to professional development work, encouraging teachers to create ongoing study groups, and providing space (and even snacks) for their meetings.

There are other costs associated with providing a challenging science program as well. Some, like budgeting for materials (e.g., storage bins, meter sticks, probes, overhead projectors, transparencies and markers) and anticipating replacement costs may seem small. However, having these materials in good supply and good shape can make the difference between smoothly running, productive classes and ones that never get off the ground. Other costs, like support for capital investments in technology, will help ensure that students have access to tools that facilitate science learning. Once you have purchased equipment, it is also important to commit resources for maintenance and upkeep. No one wants computer labs to sit empty for lack of useful software or the technical support needed to keep the machines in working order.

Community outreach

Educating the community about changes in science education and building community support for the district's science program are important responsibilities that fall in large part to administrators. Parents and guardians may have difficulties understanding the new approaches to science education and will look to school and district leadership for information about their value. Parents often voice two major kinds of concerns. One is whether their children are getting an adequate science education. For those parents whose own science education emphasized memorization and "cookbook" labs, the new emphasis on science inquiry may be unfamiliar and of questionable rigor. The second concern relates to how they can help their children with their science studies.

What science is my child learning at school? One way to help allay parents' concerns about the rigor and appropriateness of the science curriculum is to hold informational meetings to describe and discuss new approaches to science teaching and learning. Some schools have found that showing videotapes of their students engaged in thoughtful inquiry, posing questions and hypotheses, and planning ways to gather information to address their ideas, can offer parents concrete images of the kind of thinking, investigation, and understanding that lies at the heart of science education reform. Another way to inform parents about the science their children are learning is to give them the chance to explore some of the lessons or activities themselves. Consider holding a "parent science night" that includes time to engage in some of the scientific thinking and investigating that their children experience. A science night would also provide a time for teachers to help parents identify the important science concepts and inquiry skills their children are learning in class.

Administrators can also help promote community-wide understanding of science education reform by steering parents to other resources. There are a number of web sites that provide useful starting points for parents interested in learning more about science education.

- The AAAS and the National Science Foundation collaborate on hosting a web site with links to specific science resources and sites that support parents' general participation in their children's education.
- The Eisenhower National Clearinghouse (ENC) offers an extensive set of resources for mathematics and science education. It devotes a section of its "Topics" page to issues regarding parent involvement.
- The NSTA web site includes a "Help for Parents" section as part of its online resources.
- The U.S. Department of Education also has resources for parents, including a booklet specifically about helping children learn science. While this booklet is written for parents of preschool and elementary school-aged children, it offers ideas for exploring science questions with children that can help parents imagine how they might encourage children of any age to observe, question, hypothesize, and investigate.

Another strategy for community outreach is to share data with parents about student learning. The developers and publishers of a number of standards-based curricula report on the mathematics achievement of students who have used their materials (see the K-12 Science Curriculum Dissemination Center web site at for links to developers' web sites). The U.S. Department of Education web site also links to reports of student achievement.

Use data about your students' performance to inform conversations with the community about how current educational policy, curriculum, and instruction contribute to the development of scientifically literate students and how these could be modified to promote even stronger science teaching and learning. You can also use close analysis of district-based information about students' strengths and weaknesses to fine-tune curriculum and instruction. Remember, too, that it may take some time between the beginning of efforts to implement new curricula or teaching practices and the point at which you can expect to see changes in measures of student achievement (Goldsmith, Mark, & Kantrov, 1998).

How to help at home? Parents and guardians are often concerned that they are unable to help their children with their science homework because their own school experiences were so different from the work their children are doing. Holding "science nights" at school is one way to give parents a better sense of the kind of work their children do class and to offer some ideas about how to help children approach their homework. Another is to assure parents that their children have access to additional resources, should students need more help. You can, for example, compile and distribute lists of particularly informative Internet science sites for parents and children to visit together. Some schools also establish homework centers or tutoring programs to ensure that students are getting the support they need to succeed in science class.

Summary

Improving students' scientific understanding and performance is a major undertaking. It requires making significant changes to both science curriculum and instruction. If this undertaking is to be successful, it will require the active support and participation of all stakeholders in our students' education. Administrators can promote and support science education reform in a number of important ways. These include the following.

- Learn about the goals and approaches of science education reform.
- Be strategic about getting reform going in your district. Identify the places where need is greatest, and make a clear plan for addressing those needs at both district and school levels.
- Take advantage of the resources available nationally, regionally, and in your own community.
- Remember that professional development is key to implementing new approaches to teaching and learning. Make professional development an ongoing part of the school culture for teachers and administrators alike.
- Commit resources, both financial and material, to science education.
- Bring parents and other community members into the equation. Encourage them to learn more about science education reform, to express an interest in their children's science courses and, where feasible, to explore science questions and concepts with them.

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Suggested Web Sites

Association for the Advancement of Science (AAAS): www.aaas.org AAAS/NSF parent web site: www.parentsinvolved.org

Annenberg/CPB: www.learner.org *The Annenberg/CPB Guide to Math and Science Reform*: www.learner.org/theguide

Biological Sciences Curriculum Study (BSCS): www.bscs.org

Eisenhower National Clearinghouse for Mathematics and Science Education (ENC): www.enc.org

Exploratorium: www.exploratorium.org

K-12 Science Curriculum Dissemination Center: www.edc.org/cse

Middle Grades Science Webquests: www.what-is-the-speed-of-light.com/webquests/science-webquests-index.html

National Science Teachers' Association (NSTA): www.nsta.org

National Science Foundation (NSF): www.nsf.gov

Project 2061: www.project2061.org

U.S. Department of Education: www.ed.gov

Footnote

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Donna F. Berlin, Arthur L. White

Attitudes Toward Integration as Perceived by Preservice Teachers Enrolled in an Integrated Mathematics, Science, and Technology Teacher Education Program

The results of the quantitative analyses indicate that preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education were positive upon completion of the program, though less positive than expressed prior to beginning the program.

The mathematics, science, and technology education communities are undergoing major reform in curriculum design, instructional approaches, and assessment practices. National standards for content, professional development, and assessment have been developed for mathematics, science, and technology education in the United States (National Council of Teachers of Mathematics, 1989, 1991, 1995, 2000; National Research Council, 1996; International Technology Education Association, 2000). Although promoting discipline-specific standards, these reform documents also recognize and recommend connections between and among the disciplines.

> It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others. (American Association for the Advancement of Science, 1993, p. 3)

Given the nature of the reform efforts, along with national goals for student achievement in mathematics and science, there is no doubt that we are in a new era where educators in mathematics, science, and technology must find ways to join forces to meet the curricular challenge before them.

> The science and mathematics are important to the understanding of the processes and meaning of technology. Their integration with the technology education curricula is vital. (Johnson, 1989, p. 3)

Given the nature of the reform efforts, along with national goals for student achievement in mathematics and science, there is no doubt that we are in a new era where educators in mathematics, science, and technology must find ways to join forces to meet the curricular challenge before them. The consistent message heard across the disciplines emphasizes the need to collaborate, integrate, focus on literacy, facilitate inquiry and problem solving, and provide educational experiences that are of value to all students regardless of background

To enable teachers to provide an integrated teaching and learning environment, changes in teacher preparation are essential.

or aspirations. To enable teachers to provide an integrated teaching and learning environment, changes in teacher preparation are essential.

Various attempts have been made to integrate science and mathematics methods courses in teacher education programs (Foss & Pinchback, 1998; Haigh & Rehfeld, 1995; Huntley, 1999; Lonning & DeFranco, 1994; Lonning, DeFranco, & Weinland, 1998; Miller, Metheny, & Davison, 1997; Stuessy, 1993; Stuessy & Naizer, 1996; Watanabe & Huntley, 1998). These courses most often have been targeted at the preparation of preservice elementary or middle school teachers. Very few integrated science and mathematics methods courses have been designed for preservice secondary school teachers (see, for example, Austin, Converse, Sass, & Tomlins, 1992).

Inservice professional development opportunities generally have been designed for practicing teachers to develop integrated science and mathematics activities/units (Francis & Underhill, 1996; Slater, Coltharp, & Scott, 1998; Underhill, Abdi, & Peters, 1994) or to use specific integrated science and mathematics curriculum materials such as Activities Integrating Math and Science (AIMS; Deal, 1994; Nye & Thigpin, 1993) and Teaching Integrated Mathematics and Science (TIMS; Goldberg & Wagreich, 1991; Isaacs, Wagreich, & Gartzman, 1997). A few inservice professional development opportunities integrate technology education, along with science and mathematics education (James, Lamb, Householder, & Bailey, 2000; LaPorte & Sanders, 1993; Meier, Cobbs, & Nicol, 1998; Scarborough, 1993a, 1993b; Wicklein & Schell, 1995).

The literature associated with teacher preparation and integrated science, mathematics, and technology education is laden with obstacles or barriers including philosophical and epistemological differences among the disciplines, teacher content and pedagogical content knowledge in the disciplines, teacher perceptions and beliefs, school and administrative structures, assessment practices, and appropriate instructional resources (Czerniak, Weber, Jr., Sandmann, & Ahern, 1999; Lehman, 1994; Lehman & McDonald, 1988; Meier et al., 1998; Pang & Good, 2000; Wicklein & Schell, 1995). In the face of this challenge, however, is a consistent vision of teacher preparation for integrated teaching and learning in middle and secondary school levels that is characterized by peer collaboration and team teaching.

Master of Education Program in Integrated Mathematics, Science, and Technology Education

Goals and Objectives

The purpose of the Master of Education (M.Ed.) Program in Integrated Mathematics, Science, and Technology Education (MSAT Program) at The Ohio State University is to provide a comprehensive master's program in integrated mathematics, science, and technology education, leading to the following teacher certifications dependent upon the baccalaureate major: mathematics, biology, earth science, chemistry, physics, and comprehensive science for grades 7-12; technology education for grades K-12; and integrated math/science for grades 4-9. For admission into the program, applicants must have completed a bachelor's degree with 70 quarter hours of mathematics, science, and/or technology; a 2.7 grade point average (GPA) overall; a 2.7 GPA in the undergraduate major; and a 2.7 GPA in mathematics, science, and technology course work. Applicants must submit scores from the GRE General Test.

Consistent with the national standards in mathematics, science, and technology education and state certification requirements, the MSAT preservice teachers acquire a solid background in content knowledge through their work in both their undergraduate major and graduate M.Ed. program. The courses in the MSAT M.Ed. Program are designed to develop preservice teacher understanding of educational foundations, cognitive science and developmental theory, pedagogical content knowledge, assessment, and the use of technology, all to meet the needs and interests of diverse learners and special populations. Moreover, the MSAT M.Ed. program identifies and advances connections among the sciences and between mathematics, science, and technology, thereby providing a unique academic structure to prepare teachers at middle and secondary school levels.

The MSAT program focuses on the connections between and among theory, research, development, practical application, dissemination, and communication related to mathematics, science, and technology education.

Such connections will enable these traditionally separate discipline areas to share human, physical, and fiscal resources for a more holistic preparation of teachers and other education-related professionals.

The MSAT Program is a five-quarter program leading to teacher certification and a Master of Education degree. Two ubiquitous elements of the program are: (1) the integration of science, mathematics, and technology education through specially designed, team-taught content and methods courses and (2) a focus on current theory and research culminating in a preservice, teacher designed and implemented, action research project.

The objectives of the MSAT M.Ed. Program are to prepare prospective teachers who:

The MSAT program focuses on the connections between and among theory, research, development, practical application, dissemination, and communication related to mathematics, science, and technology education.

- demonstrate a commitment to **all** students and interact with students in ways that promote fairness, integrity, and respect for each individual;
- recognize how students differ in terms of race, gender, socioeconomic status, cultural heritage, learning styles, and special needs and appreciate this diversity;
- have knowledge of and are able to promote the intellectual, physical, social, emotional, ethical, and cultural growth of students;
- understand how students learn and apply the ideas from prevailing learning theories in their practice;
- have a thorough content understanding, both conceptual and procedural knowledge, in the subjects they teach, and value scholarship in the disciplines;
- understand the connections both within and among the disciplines, and value and use interdisciplinary approaches to education;
- create caring and inclusive learning environments that are developmentally appropriate and responsive to the needs and characteristics of diverse student populations;
- create stimulating and challenging learning environments in which students accept responsibility for learning, take intellectual risks, develop confidence and self-esteem, and work independently as well as collaboratively;
- create learning opportunities for the development of communication, critical thinking, inquiry, problem solving, and higher order thinking skills in their students;
- have extensive, general, pedagogical knowledge and content-specific pedagogical knowledge, and apply this knowledge along with a rich understanding of the learner to curricular decisions, to the selection of appropriate instructional strategies, and to the development of instructional plans that are equitable and adaptive to diverse learners and special populations;
- monitor and evaluate student learning and progress through a variety of formal and informal assessments that are aligned with educational objectives and are sensitive to student diversity and exceptionality, and can clearly communicate the results of these assessments;
- recognize the need to connect curriculum, instruction, and assessment, and make decisions with this alignment in mind;
- support and improve teaching and learning with a well-infused use of technology in appropriate and meaningful ways;
- understand that family and community support are essential in meeting the needs of students and families in urban and other learning environments, and in particular, for economically- disadvantaged and at-risk youth;
- understand that schooling occurs in a social and political context and that classrooms are social systems that function within and in relation to a broader context;
- value reflection as a basis for decision-making and as a component of professional growth;
- regularly reflect on and systematically inquire into their practice and adjust their teaching accordingly;
- collaborate and team with peers and other education professionals to strengthen the school programs and improve practice; and

- engage in lifelong learning as an individual and as a member of the teaching profession.

These objectives have guided the development and implementation of the courses and field and clinical experiences for the MSAT M.Ed. Program and serve as a standard by which to monitor, evaluate, and improve the program.

MSAT M.Ed. Program Coursework

The MSAT M.Ed. Program assumes five quarters of full-time registration, beginning in the summer and continuing through the following summer. Preservice teachers have opportunities to take specialty content courses related to state certification requirements in mathematics, the sciences, or technology education throughout the program. Applicants who enter with more than 70-quarter hours in their mathematics, science, or technology undergraduate major and have fulfilled the core requirements for the teaching field may be exempted from some of the specialty content courses. Credit hours in the MSAT M.Ed. Program can range from to 63 to 78 quarter hours, depending on certification area and previous coursework.

See Figure 1 for the schedule of classes, course titles, and quarter credit hours.

Figure 1. MSAT M.Ed. Program coursework.

First Summer Quarter	
Integrated Pedagogy I (Standards)	3 credits
Integrated Content I (Mst)[1]	3 credits
Fundamental Ideas of School Mathematics	3 credits
Learning and Cognition	3 credits
Research Methods	3 credits
Specialty Content Course	3 credits
	18 credits
Autumn Quarter	
Integrated Pedagogy II (Methods)	3 credits
Integrated Content II (Smt)[2]	3 credits
Fundamental Ideas of School Science	3 credits
Internship (Middle/High School)	3 credits
Clinical Experience	3 credits
Specialty Content Course	3 credits
	18 credits
Winter Quarter	
Integrated Pedagogy III (Diversity & Equity)	3 credits
Integrated Content III (Tms)[3]	3 credits
Fundamental Ideas of School Technology	3 credits
Specialty Methods	3 credits
Internship (Middle/High School)	6 credits
	18 credits
Spring Quarter	
Student Teaching (Middle/High school)	10 credits
Student Teaching Seminar	2 credits
	12 credits
Second Summer Quarter	
Capstone Seminar	3 credits
Specialty Content Course(s)	9 credits
	12 credits

[1]Mst – focus on mathematics content with connections to science and technology content.
[2]Smt – focus on science content with connections to mathematics and technology content.
[3]Tms – focus on technology content with connections to mathematics and science content.

MSAT M.Ed. Exit Requirements

Preservice teachers must complete an action research project and a comprehensive examination as exit requirements of the MSAT M.Ed. Program. In the final quarter of the program, each preservice teacher writes a 4-hour examination in mathematics, science, and technology education. Focused on mathematics, science, and technology education, the examination is typically divided into three parts: (1) Foundations of Education (1 hour), (2) Curriculum and Instruction (2 hours), and (3) Candidate's Question Related to Action Research Project (1 hour).

Preservice Teacher Attitudes Toward Integration

Both quantitative and qualitative data were collected to explore preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education. The results of the qualitative analysis were used to review, modify, and build upon the results of the quantitative analyses so as to develop a more comprehensive understanding of the attitudes and perceptions of the preservice teachers.

Subjects

The MSAT M.Ed. cohort group for year 1 of the program included 37 preservice teachers. Table 1 describes the M.Ed. preservice teachers by gender and major.

Instruments

A 20-item semantic differential was used to measure preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education (SD-MSAT). The semantic differential consisted of a 5-point scale with a range of 20 to 100. The scoring of the semantic differential was determined by asking each faculty member to indicate what s/he perceived to be the ideal integration-related outcome of the teacher education program. These responses were tallied and averaged to obtain the weighting for each response for each item. The semantic differential was administered as a pretest and posttest. Cronbach's standardized alpha, an estimate of internal consistency reliability, for the instrument are as follows: .88 pretest SD-MSAT and .86 posttest SD-MSAT. At both the beginning and end of the program, one open-ended, free-response question was administered – What does the integration of mathematics, science, and technology education mean to you?

Table 1

Sample Distribution

	Major			
	Math	Science	Technology	Total
Males	8	12	1	21
Females	6	10	0	16
Total	14	22	1	37

Data Collection Procedures

All instruments to collect both quantitative and qualitative data were administered prior to the beginning of coursework at the start of the June orientation meeting. All instruments were administered again at the completion of the program, at the end of the Capstone Seminar. It should be noted that since there was only one technology education major in the sample, his data were omitted from the analyses.

Quantitative Analyses and Results

Table 2 reports the means and standard deviations for the pretest and posttest attitudes and perceptions related to the integration of mathematics, science, and technology education by major and gender. A multivariate analysis of variance was used to identify significant main and interaction effects of major, gender, and trial for the semantic differential to measure preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology. There were no significant interaction effects and only one significant main effect, the trial effect. Table 3 presents the results of the univariate analysis of variance.

Table 3 reveals that there is a significant difference between preservice

Table 2

Means and Standard Deviations for Pretest and Posttest Attitudes and Perceptions Related to the Integration of Mathematics, Science, and Technology Education

		Major				
		Math		Science		Total
		Male	Female	Male	Female	
Pretest	**M**	83.6	79.5	82.8	84.9	83.0
	SD	5.6	6.9	3.8	4.7	4.9
Posttest	**M**	69.8	78.5	74.2	81.3	75.9
	SD	22.1	7.0	12.0	9.0	13.1

Table 3

Univariate Analysis of Trial Effect for Pretest and Posttest Comparisons for Attitudes and Perceptions Related to the Integration of Mathematics, Science, and Technology Education

Attitudes and Perceptions	MS_E	F (1,22)	p
Integration of Mathematics, Science, and Technology Education	89.07	5.89	.024*

* p < .05.

teacher scores on the pretest and posttest for attitudes and perceptions related to the integration of mathematics, science, and technology education, $F(1,22) = 5.89$, $p = .024$. Inspection of the means for the semantic differentials related to the integration of mathematics, science, and technology education reveals that preservice teacher scores on the posttest ($M = 75.9$, $SD = 13.1$) were significantly lower than on the pretest ($M = 83.0$, $SD = 4.9$).

Qualitative Analysis and Results

Preservice teacher responses to the question "What does the integration of mathematics, science, and technology education mean to you?" were subjected to a process of iterative review to identify regularities and emergent patterns associated with preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education upon entering the program and upon completion of the program. Recurrent statements of interest, importance, and salience to the MSAT M.Ed. Program were identified and coded. Categories were generated to organize the data into manageable units for the purpose of synthesis and explication.

Three categories were identified to construct a parsimonious, but comprehensive, framework for the analysis. Preservice teacher responses were categorized as curricular, barriers/challenges, or student benefits and examined for consistencies or variations from the onset to the completion of the program.

Curricular patterns. Prior to participation in the MSAT M.Ed. Program, preservice teachers were more likely to note the commonality among the subject areas and the need to provide a cohesive education program through the integration of mathematics, science, and technology education. Examples related to this perspective are as follows:

> Combining all science, math & technology education so as to make a more integrated and comprehensive education program. (Preservice Teacher 10)

> Integration of Math, Science, and Technology in Education means combining the three areas into one through the creation of collective lessons and projects that exhibit aspects of each area but without isolating one area of study from another. (Preservice Teacher 35)

Upon completion of the MSAT M.Ed. Program, preservice teacher perception of the role of integration in the curriculum was less dogmatic and less pervasive. Many preservice teachers were more comfortable with the term "connections" and suggested the need for appropriate, "natural and necessary" (Preservice Teacher 15), integrative experiences.

> Sometimes it can be beneficial if the integration is gradual and not forced …" (Preservice Teacher 17)

> Finding connections/relationships between math, science, and technology. (Preservice Teacher 9)

> Combining the content and methods of these subjects in order to make connections in these areas. (Preservice Teacher 13)

> Integration of this topic means to ensure that when appropriate a proper fit should be found. I do not believe that integration works when these areas are forced upon each other. (Preservice Teacher 24)

Barriers/challenges. None of the preservice teachers mentioned any barriers or challenges in their pre-program statements. Their initial, intuitive comfort with the integration of mathematics, science, and technology education appeared to be idealistic and naíve. This was not the case at the end of the program. After completing the program coursework including clinical experiences, field experiences, and a quarter-long internship, preservice teacher perceptions of the integration of mathematics, science, and technology education were more practical and realistic. They recognized that it was a difficult and complex task to find or develop "appropriate connections" (Preservice Teacher 26) and "non-trivial applications" (Preservice Teacher 39) to integrate mathematics, science, and technology education, and that issues of public perception, time constraint, collaboration, and resources were obstacles.

Preservice Teacher 42 eloquently captures the perception of integration at the end of the program.

> Teaching teachers and teachers-to-be the importance of integrating, connecting, and aligning math, science, and technology in education along with strategies and tactics for such integration. I think we all know that the subjects should be integrated, but the difficulty lies in how to integrate and the practicality of the integration in actual school settings.

Student benefits. Responses at the onset and at the completion of the program were similar with regard to student benefits associated with the integration of mathematics, science, and technology education. Support for integration was most frequently couched in the opportunity to provide real world applications for school mathematics, science, and technology. Preservice teachers perceived these applications as more relevant to students, and consequently would benefit student understanding and improve student attitude.

> It means preparing students for the future because in the real world the three are not separate but intertwined. Therefore, in the classroom the three need to be integrated. (Preservice Teacher 2)

> This integration will provide students with a broader view of the world, and it will help them see how everything in the world interrelates. (Preservice Teacher 4)

> It means that (finally) someone has realized the need to teach math and science within an applied context so that students will be able to apply these skills in a practical way. (Preservice Teacher 8)

> For me it means teaching mathematics by bringing science and technology in the classroom. This should result in an increased interest and understanding of mathematics. (Preservice Teacher 10)

> Showing how math, science, and technology are related and using these relationships to build bridges to understanding. They are dependent upon one another and it makes no sense to learn one thing without the other. (Preservice Teacher 25)

> Students often ask when are they going to use certain information and how is a particular concept related to other material. Integrating the sciences provides students with real life examples of how the sciences are related. (Preservice Teacher 27)

> A lot of applications — use the math/science/technology to solve practical problems. (Preservice Teacher 30)

Conclusions and Discussion

The results of the quantitative analyses indicate that preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education were less positive upon completion of the MSAT M.Ed. Program. However, preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education were still clearly positive, though less positive than expressed prior to beginning the program. It is interesting to note that the variability on the posttest is considerably greater than on the pretest, indicating a more diverse view of the integration of mathematics, science, and technology education. It appears that preservice teachers who experienced the MSAT M.Ed. Program demonstrate variant, but positive attitudes and perceptions related to the integration of mathematics, science, and technology education. Coupled with the results of the qualitative analysis, the downward change in preservice teacher attitudes and perceptions related to the integration of mathematics, science, and technology education may be related to a more realistic, practical, and cautious approach to this integration. This interpretation is consistent with the results of Lehman (1994) and Lehman & MacDonald (1988), who found that preservice teachers were less knowledgeable and more positive about integration than experienced, practicing teachers. Future research involving subsequent cohort groups in the MSAT M.Ed. Program is planned, along with the collection of additional data such as preservice teacher interviews; preservice teacher beliefs about the nature of mathematics, science, and technology education; preservice teacher understanding and implementation of inquiry methods; mentor teacher interviews; and follow-up observations and interviews of graduates.

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The Debate Over Dissection: Dissecting a Classroom Dilemma

As the debate over dissection in the classroom continues, attention is being paid to the benefits of actual dissections, as well as to the advantages of dissection alternatives for the science education of students.

Policy makers, curriculum developers, administrators, teachers and students across the country have begun to reevaluate the science curriculum and scrutinize the role of dissection in science teaching—particularly in the science classroom. Recently, a new wave of court cases and legislation has brought nonhuman animal dissection to the forefront of science education issues. Also, teachers, students, and parents are questioning the value of classroom dissection. Some dissection objections stem from animal rights concerns, students' moral values, and parental concern for the emotional well being of students. From a different perspective, many teachers fear the loss of academic freedom in the classroom and the possibility of a less effective educational environment resulting from this controversy.

Although there has been increasing interest on the issue of animal dissection, little attention has been given to the issue in educational publications. There is still a dearth of research on dissection as a tool for learning, but animal dissection certainly deserves analysis on the part of science teachers and concerned educators. Data must bring both student and teacher opinion and the value of dissection as a learning technique into consideration. Findings from a student poll published in the North Carolina Science Teachers Association's (NCSTA) *The Journal* (Hounshell and Hill, 1996) indicate that over one third of the students polled do not enjoy dissection. Of those who enjoy it 53% said they enjoy it only 'a little' and 36.1% think you learn only 'a little.' As far as mandating dissection, 63% of students polled believe dissection should not be a required activity in science classes. Still, Hounshell and Hill recognize the limits of past studies by commenting that "incredibly, with all the dissection in elementary, middle school, and high school, we do not have research evidence either to support or refute dissection as a classroom strategy." A 1993 scientific study published by the *Journal of Research in Science Teaching* examined "The Effects of an Interactive Dissection Simulation on the Performance and Achievement of High School Biology Students" (Kinzie, Strauss, and Foss). The experimental findings suggested that IVD (Interactive Videodisk-based) simulation was at least as effective as actual dissection in promoting student learning of frog anatomy and dissection procedures." However, the most effective strategy carried out in this study was IVD simulation used as a preparation for actual dissection. Participants in this trial performed subsequent dissections much more effectively, achieved more of the activity goals, and retained more knowledge than both the dissection-only and IVD-only groups.

Where They Stand

Leading national organizations recognize the immediate need to address the "dissection issue," and many groups have published position statements concerning dissection in the science classroom. Often, groups such as the National Science Teachers Association (NSTA) and the National Association of Biology Teachers (NABT) leave the issue of dissection to the teacher's discretion in his/her particular environment. NSTA's position [see figure 1] states that animal dissection "enables students to develop skills of observation and comparison, a sense of stewardship, and an appreciation for the unity, interrelationships, and complexity of life." Still, this NSTA position statement stresses that teacher supervision and effective, responsible instruction are essential. Teachers must provide a safe, knowledgeable and respectful environment for dissection labs. The NABT promotes a similar policy. When confronted with the dilemma of whether to dissect in the classroom, NABT states "biology teachers are in

A variety of alternatives have been designed to meet the needs of teachers for the study of anatomy and physiology.

the best position to make this determination for their students" as long as dissections are "conducted within the long established guidelines of proper care and use of animals, as developed by the scientific and educational community." As far as alternatives to dissection, NABT encourages teacher sensitivity to student objections, but also believes that "no alternative can substitute for the actual experience of dissection" (1995).

Alternatives to Dissection

A variety of alternatives have been designed to meet the needs of teachers for the study of anatomy and physiology. Anatomical models can be used to depict the physical appearance and complexity of animal structures and functions. Many of these models are designed to let the student take apart and reconstruct animal structures. Another alternative is a video presentation that covers the process of dissection. Photographs and slides can also be used to explore animal anatomy and physiology. The most recent technological alternatives to dissection include Interactive Videodisks (IVD's) that allow students to carry out a dissection on the computer with the ability to focus on any layer of tissue at any step of the dissection process for an animal. "Virtual" animal dissections are also found using the Internet, and this shareware can be accessed freely on the Internet. All of these alternative materials are readily available for science teachers. The Humane Society of the United States offers an "Humane Education Loan Program (HELP)," in which schools can borrow materials including slides, charts, models, and computer simulation for 17 different animals (1998). For teachers who believe the use of actual organisms is the only means to teach anatomy and physiology, one alternative to dissection is to use animal parts from grocery store meat counters. For more advanced study, items such as cow's hearts, brains, intestines, and eyes can be requested at slaughterhouses.

State legislators throughout the United States have responded to the dissection controversy. A review of "Student Choice Laws" in the United States [see figure 2] indicates that over six states have already passed or have proposed laws related to the dissection issue. Already, California, Florida, Illinois, New York, Pennsylvania, and Rhode Island have passed legislation securing the rights of students to refuse

Figure 1: An NSTA Position Statement

Guidelines for Responsible Use of Animals in the Classroom

- ❑ Acquisition and care of animals must be appropriate to the species.
- ❑ Student class work and science projects involving animals must be under the supervision of a science teacher or other trained professional.
- ❑ Teachers sponsoring or supervising the use of animals in instructional activities—including acquisition, care, and disposition—will adhere to local, state, and national laws, policies, and regulations regarding the organisms.
- ❑ Teachers must instruct students on safety precautions for handling live animals or animal specimens
- ❑ Plans for the future care or disposition of animals at the conclusion of the study must be developed and implemented.
- ❑ Laboratory and dissection activities must be conducted with consideration and appreciation for the organism.
- ❑ Laboratory and dissection activities must be conducted in a clean and organized work space with care and laboratory precision.
- ❑ Laboratory and dissection activities must e based on carefully planned objectives.
- ❑ Laboratory and dissection objectives must be appropriate to the maturity level of the student.
- ❑ Student views or beliefs sensitive to dissection must be considered; the teacher will respond appropriately.

NSTA Handbook 2000-01. p. 188

Figure 2

ACROSS THE U.S

A Look at Student Choice Laws

▪**California** A public school student (K-12) with moral objection to dissection can notify his or her teacher. The objection is to be substantiated by a note from his or her parent or guardian. The teacher may then work with the student to develop an adequate alternative educational project of comparable time and effort. Any teacher teaching a course using live or dead animals is to inform the pupils of their right to object.

▪**Florida** Students in public or non-public schools (K-12) may be excused from dissection and animal experiments with written requests from their parent or guardian. No surgery or dissection may be performed on any living mammal or bird.

▪**New York** Any student in a public school with moral or religious objection to performing or witnessing the dissection of an animal will be provided with an opportunity to complete an alternative project without penalty. A written note from the parent or guardian is required to substantiate the objection. Experiments on live animals are forbidden.

▪**Pennsylvania** Public or non-public school students (K-12) may refuse to dissect animals and choose an alternate project that can not be discriminated against based upon the decision to exercise this right. Schools must notify incoming students and their guardians of the right to decline to participate in an educational project involving the harmful or destructive use of animals not less than three weeks prior to the scheduled course exercise involving the use of animals. Lowering a grade because a pupil has chosen an alternative education project is strictly prohibited.

▪**Rhode Island** A parent or guardian of any student (K-12) may refuse to allow their child to dissect any animal or part of an animal. Schools must provide students with alternative materials and exercises that have the same learning objectives. Teachers can not discriminate against students or lower their grades for choosing an alternate project.

▪**Louisiana** Each city or parish school must offer alternative project to any student (K-12) which chooses not to perform, participate in, or observe the dissection of animals. The alternate project must be comparable in learning objectives, as well as in time and effort. They must not be used as a means of punishment. Students may also request alternate examinations if the examinations include them to participate in or observe dissection. Any teacher instructing a course that includes the use of live or dead animals is required to inform students of their rights prior to instruction.

▪**Maryland** All public school systems have an unofficial agreement to provide alternatives to dissection at the request of students or parents. This agreement was substantiated in writing on a survey that was published in 1995 and distributed by the State Department of Education. State law requires schools to publish course descriptions including dissections, alternatives, and how to gain access to alternatives.

Already, California, Florida, Illinois, New York, Pennsylvania, and Rhode Island have passed legislation securing the rights of students to refuse animal dissection without penalty.

animal dissection without penalty. Teachers in these states must provide objectors with an alternative project by law. Such legislation is under consideration in Massachusetts as well (Lewis, 1997). According to an article published by the Humane Society of the United States, the Illinois Dissection Alternatives Act (HB 3254), signed by Governor George Ryan in June of 2000, also acknowledged that “in certain circumstances these new technologies are capable of providing an education experience superior to dissection, and they have proven to be less expensive and more humane” (2000). Although alternatives must be provided for dissenting students, the New York State Education Department Science Bureau believes that dissection of animal and plant specimens in high school biology laboratories is a valid instructional enterprise. However, every effort should be made to derive as much educational value from each dissection as possible” (1990).

The Debate Among Educators

A broad spectrum of ideas on dissection exists in the science education community. Science educators and professionals alike are engulfed in the dissection debate [see figure 3]. *The Science Teacher* called attention to the debate through an article styled as a forum on dissection. In this discussion article, proponents of dissection cited that “a model or series of slides depicting an animal does not relate the intricacy of the internal anatomy or explain how that intricacy is functionally significant to that creature’s environment” (Keiser and Hamm 1991). Dissection advocates believe that total sensory, hands-on experience of dissection prepares students for future careers and gives them an appreciation of the complexity of the natural world. They also claim that computer simulated dissections are not as effective as actual dissections, and that a “transition must be made from model to reality” (Keiser and Hamm, 1991). Barbara Orlans (1991) is a leader in the opposition to dissection. She supports the case against dissection by raising several concerns, including “the domination of the curriculum by dissection at the expense of other important aspects of biology.”

Figure 3: Dissection Debate

Opposing Viewpoints on Dissection

Among the arguments in favor of dissection are:

1. It’s a hands-on experience that allows students to participate in a personal exploration.
2. It allows students to see and learn the physical placement of organs, the appearance and texture of tissues and organs, and the relationship of structures with one another.
3. It illustrates the idea that the animal body is a complex arrangement of functioning organs.
4. It develops manual dexterity in using dissection instrumentation.

The opponents of dissection use the following arguments:

1. It’s a desensitizing experience for the students.
2. It can be perceived as condoning the desecration of a dead body.
3. Students might do a poor dissection; the activity becomes a “hack and slash” experience. The amount of information learned is often less than and inferior to that gained from a lesson without dissection.
4. It is not moral to harm animals when there is no compelling reason and when alternative activities can teach the same content and skills.
5. High school biology should emphasize contemporary subjects such as genetics, cell biology, etc., with an emphasis on teaching and thinking, not memorization.
6. Dissection does not foster a reverence for life. This should be a part of the objectives of a biology course.

Taken from The Responsible Use of Animals in Biology Classrooms. (NABT)

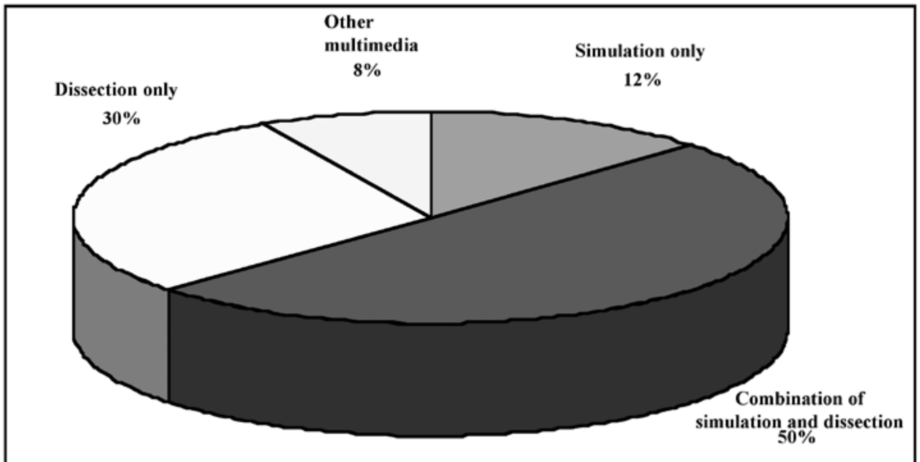
A broad spectrum of ideas on dissection exists in the science education community.

In a survey of biology teachers conducted by the author [see figure 4], 30% of the biology teachers surveyed across North Carolina responded that they still choose to use “only” dissection in their classrooms. While 50% of the teachers combined the use of simulation and actual dissection into their curriculum, 20% used either “only” simulation or some other form of multimedia, but no actual dissection. The teachers surveyed demonstrated varying opinions when asked about their perception of dissection in the high school biology classroom. One teacher, who said that she felt computer simulations were improving but still could not compare to an actual dissection, still allowed some concern over classroom dissection as she wrote, “I will say though that when all the pigs were bagged up at the end of the dissection, waiting for our disposal person to pick up, I felt badly about the waste.” Another teacher said she felt that “the level of sophistication and academic preparation required to fully appreciate a dissection are not present at the high school level.” Yet, some of the teachers polled felt that classroom

Figure 4

Dissection in the Classroom

Which Practices Are Teachers Using?



What High School Biology Teachers Think on the Dissection Issue

dissection was a vital component of the high school science curriculum. Still others felt frustrated with proponents of alternatives to actual dissection. One such teacher responded, "Those who push alternatives do not give us alternatives [funding]."

When confronted with the need for an immediate, decisive opinion on the role of dissection in science classrooms, it is clear that dissection can play a valuable role in education. Students should not be denied the opportunity to learn through actual animal models. However, these students must be maturely guided by effective educational supervision in order to obtain educational value from dissection. Students must be at a level where they can intellectually benefit, not emotionally suffer, from dissection labs. For this reason, complicated, in depth dissection practices should be reserved for more advanced high school classrooms.

As the debate over dissection in the classroom continues, great attention must be paid to the benefits of actual dissection, as well as to the advantages of dissection alternatives for the science education of students. Priority must be given to investigating which methods of teaching anatomy and physiology have the most positive effects on the students' learning of and interest in the material. Clearly, more research is needed to determine the extent dissection should be used in the science curriculum. Although politics and public opinion have continued to fuel the dissection debate, our teachers are inevitably the deciding factor as controversy is played out in their classrooms.

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Jennifer Fischer-Mueller, Dana L. Zeidler

A Case Study of Teacher Beliefs in Contemporary Science Education Goals and Classroom Practices

Results are presented from an examination of teachers' beliefs in contemporary goals of science education and the degree to which these beliefs are embedded in classroom practices.

Introduction and Purpose

Since the Sputnik days of the 1960s, numerous research studies have revealed the need for necessary changes in science education, but few of the innovations and recommendations have been implemented (Biological Sciences Curriculum Study [BSCS], 1993; Fullan, 1993; Hart & Robottom, 1990). The research shows that much science curricula is still centered around teachers' lectures, textbooks, and student memorization of voluminous facts (American Association for the Advancement of Science [AAAS], 1993; BSCS, 1993; Hart & Robottom, 1990; National Science Teachers Association [NSTA], 1992). This style of pedagogy is contrary to the way science is practiced and inimical to the central goal of science education for the 21st century, science literacy for all students (National Research Council [NRC], 1996; NSTA, 1992; AAAS, 1993; Siebert & McIntosh, 2001).

Objectives of the Study

In order to continue reform in science education beyond the dissemination of new goals by the research community, some insight about the degree to which teachers believe in the contemporary goals and whether classroom practice is changing in support of these goals is indicated. This initial study investigating the connection between these two specific factors focused on Souhegan High School in New Hampshire. Consequently, a case study that involves a detailed examination of a single group or individual better serves the purpose of this investigation.

Surveying teachers' beliefs in contemporary science education goals, observing their classroom practice, reviewing forms of assessment, and interviewing teachers sheds light on the consistencies between classroom practice and stated beliefs in contemporary goals.

Surveying teachers' beliefs in contemporary science education goals, observing their classroom practice, reviewing forms of assessment, and interviewing teachers sheds light on the consistencies between classroom practice and stated beliefs in contemporary goals. Investigating the implicit link between teachers' beliefs in the contemporary goals of science education and classroom practice allows the science education research community to probe deeper into the dilemmas associated with educational change.

Rationale for the Context of the Study

Souhegan High School was established in 1992 with an ambitious mission statement: "Souhegan High School aspires to be community of learners born of respect, trust, and courage. We consciously commit ourselves: to support and engage an individual's unique gifts, passions and intentions; to develop and empower the mind, body, and heart; to challenge and expand the comfortable limits of thought, tolerance and performance; and to inspire and honor the active stewardship of family nation, and globe." Learning communities, as defined by McLaughlin and Talbert (1993), are groups of teachers working together in a conscious effort to adapt their practice to the learning needs of students. Accordingly, Souhegan High School has become a member of the Coalition of Essential Schools (CES) and prescribes to its ten Common Principles (Sizer, 1984).

The general direction of reform in CES schools is consistent with many of the specific recommendations offered by the science education community (AAAS, 1993; NSTA, 1992; NRC, 1996, Siebert & McIntosh, 2001). These recommendations include: engaging students in their own learning; changing the teacher's role from teacher-as-expert and giver-of-information to facilitator of student centered activities; and, the mastering of skills and relevant knowledge to provide conceptual depth rather than memorization of many disconnected facts. These consistencies make a CES member school a viable place for an investigation of teachers' beliefs regarding the contemporary science education goals and teachers' routine classroom practice.

Research Questions and Corresponding Rationale

The aim of this study was to examine teachers' beliefs in contemporary goals of science education and to investigate the degree to which these beliefs are embedded in classroom practice. The following three questions provide a framework for this study's research.

R 1. To what degree do Souhegan High School science teachers support the contemporary goals of science education?

Rationale for question 1: Zeidler and Duffy (1994) and Zeidler (1998) reported surveys in which science teachers whose schools belonged to the Association for Supervision and Curriculum Development's (ASCD) High School Futures Planning Consortium III (HSFPCIII), significantly favored contemporary goals over past goal orientations. Similarly, the population for this study was high school science teachers, whose school is formally involved in issues of educational reform as evidenced by membership in CES. Moreover, this study examined routine practices of teachers using qualitative inductive data analysis. Germane research has supported the investigation of teachers' systems of thought in order to understand the key variables in implementing new curriculum (Gess-Newsome & Lederman, 1999; Mitchener & Anderson, 1989). Therefore, teachers' beliefs in the contemporary goals of science education should be uncovered if their pedagogy, as it relates to contemporary reform issues, is to be investigated.

Distinguishing strongly held beliefs from beliefs that are unimportant to a person could explain why some beliefs may be resistant to change.

R 2. What is a Souhegan High School science teacher's degree of conviction in his/her beliefs about particular goals?

Rationale for question 2: In investigating the consistencies between a teacher's stated beliefs and his/her classroom practice, the degree of conviction towards specific goals provides data for greater understanding of the actual teaching behaviors. Fishbein and Ajzen (1975) explain that the strength of a belief "is indicated by the person's subjective probability that he will perform the behavior in question" (p.12). Distinguishing strongly held beliefs from beliefs that are unimportant to a person could explain why some beliefs may be resistant to change (Zeidler, 1997).

R 3. To what extent is a teacher's purported belief in contemporary science education goals embedded in routine classroom practice?

Rationale for question 3: For students to attain the goals as outlined by the science education research community, instruction must aim toward these goals. The value of investigating teachers' thoughts relative to their classroom practice is strongly supported (Gess-Newsome & Lederman, 1999; Onosko, 1989). Hart and Robottom (1990) state that "there is a major gap between teachers' stated expectations for their students and their actual teaching practices" (p.578). Lederman and Zeidler (1987) have reported evidence of disunion in particular conceptions of science and classroom practice. By gathering data on teachers' classroom practices and their stated beliefs, occurrences of this disconnect can be better investigated. Research has also shown a basic unwillingness on the part of teachers to reorient their practice for an innovative approach (Byrd & Doherty, 1993; Anderson, 1996). During these times of educational reform, it is imperative that an examination of teachers' beliefs in current goals and the extent to

By qualitatively investigating teachers' beliefs in contemporary science education goals and observing a teacher's routine classroom practice, this study helped to gain an understanding of the connection between these two factors in science education reform.

which their classroom practice aligns with the attainment of these goals is conducted.

Significance of the Study

By qualitatively investigating teachers' beliefs in contemporary science education goals and observing a teacher's routine classroom practice, this study helped to gain an understanding of the connection between these two factors in science education reform. This is consistent with the direction of future research as outlined in the literature of current science education (Shymansky & Kyle, 1992). The studies of McIntosh and Zeidler (1988), Zeidler and Duffy (1994), and Zeidler, (1998) were significant in revealing the importance of investigating the perceptions of the contemporary goals in science education among various professionals in the study of change. Equally tantamount is the investigation of classroom practice relative to the attainment of those goals. Anderson (1992) supports the direction of studies such as the present one: "Once the desired reforms are identified, there still remains the question of what actions have the most potential for producing the desired improvements" (p.874).

Recommendations from the science education community suggest changes in current classroom practice. These suggestions are consistent with the work of Newmann, Secada, and Wehlage (1995) who define authentic pedagogy as instruction and assessment that supports "active learners" and is rooted in high standards of intellectual quality. The significance of the current study is based on the research community's need to gain a deeper understanding of teachers' beliefs in the goals and the level of engagement in authentic classroom practice that supports them. The degree to which science teachers believe in contemporary goals of science education and whether those beliefs are embedded in their actions provides a snapshot of authentic pedagogy in action.

Design and Methodology

The goal of this study was to develop grounded hypotheses and/or research questions. Given the stated research questions, a case study design most appropriately met the intended purpose of this study (Wolcott, 1992). The qualitative and quantitative aspects of this approach are described in the appropriate sections below.

Population and Sample / Instrumentation

The site of this study was Souhegan High School (SHS) in Amherst, New Hampshire, USA. This school is located in a suburban rural, middle class to upper middle class community, and is a member of the Coalition of Essential Schools (CES). For the first phase of this study, all nine science teachers on faculty participated by responding to the Contemporary Goals of Science Education Survey (Zeidler & Duffy, 1994) to assess their beliefs in these goals and their degree of conviction to the goals (see Table 1; note that items appear out of sequence because they have been "paired"). Zeidler (1998) has reported acceptable face, content and divergent validity, and reasonably high internal consistency and split-half reliability (between 0.70 and 0.87, p=. 0001).

Purposeful sampling was employed to yield three "typical case" teachers who were willing to allow an observer in their classroom and participate in multiple interviews. The procedure followed Spradley's Developmental Research Sequence (Spradley, 1980), with the goal of the research being the development of grounded hypotheses/research questions and summative comments (Glesne & Peshkin, 1992). This entailed data analyses of three types: 1) Domain Analyses – descriptive observations to define the social context; 2) Taxonomic Analyses – focused observations to examine main research question and identify potential grounded research questions; and 3) Componential Analyses – Selected observations to refine grounded research questions emerging from the previous two levels. Classroom observations were videotaped and extensive field notes support the collection of data. Case and cross-case (among the three teachers) data were coded and analyzed by discerning patterns and constantly comparing incidents to the codes to help establish clearly defined categories.

The second phase of this study included participant interviews which served multiple purposes: 1) member checking for accuracy and clarification

Table 1: Goal Statements Paired (Note: Contemporary Goals are in bold type).

31. Science education should not include career awareness.
2. Science courses should promote career awareness in the sciences.

16. The most important knowledge that a science student should have are those facts, concepts, principles, and processes that are specific to each discipline.
3. The most important knowledge that a science student should have are those facts, concepts, principles, and processes that are common to all science disciplines.

29. Science education should demand those logical, convergent thought processes that are associated with the "scientific method".
12. Science education should demand the development of divergent thought processes associated with a range of societal, personal, social, and technological problems.

30. Science education should focus on knowledge acquisition and process skill unrelated to the interactions of science, technology, and society.
4. Science education should stress the interactions among science, technology, and society.

5. Science courses should be offered in a similar ability (homogeneous) classroom.
23. Science courses should be offered in a mixed ability (heterogeneous) classroom

24. Science should be presented as value free without moral or ethical issues.
9. Science should be presented as a value laden subject that has both moral and ethical dimensions.

8. Science courses should be organized around a single discipline.
21. Science courses should be organized around themes such as energy, stability, evolution, systems, and inquiry.

25. In science courses competition among students should be encouraged.
17. Science education should stress cooperation rather than competition.

18. Science courses should help students acquire facts, concepts, and principles.
11. Science courses should help students to restructure their own knowledge, therefore acquiring new knowledge.

28. Science education should provide a learning environment where scientific understanding precludes aesthetic considerations.
19. Science education should provide a learning environment in which students are able to broaden and deepen their responses to the beauty of ideas, methods, tools, structures, objects, and living organisms.

27. Science courses should cover as many topics as possible.
15. Science courses should cover a few topics in depth.

6. Science courses should be primarily designed to produce scientists to solve scientific problems.
1. Science courses should be primarily designed to produce a scientifically literate citizenry.

20. Science education should focus on knowledge acquisition and process skill development specific to each discipline.
13. Science education should focus on attitudes, values, beliefs, risks and economic considerations related to science, technology, and society.

26. Science should be presented as a rigid, unchanging discipline.
32. Science courses should provide students with the opportunity for experiencing science as a process for extending understanding, not as unalterable truth.

14. Science education should focus on the training of future scientists.
10. Science education should stress the intrinsic nature of each subject area.

7. Science courses should emphasize inquiry skills.
22. Science education should emphasize higher order thinking skills

of classroom observation data; 2) probing deeper into participants' beliefs in the contemporary goals of science education and their classroom practice; 3) to explaining the assessment tasks; and 4) analyzing the previously established categories for definition and hypotheses/research questions development. Interviews were recorded on an audiotape and were semi-structured using the framework of Newmann et al. (1995) – (Standards and Scoring Criteria for Classroom Instruction and Assessment Tasks) as a guide.

Methodological Issues

The criteria that support trustworthiness within the naturalistic paradigm originally identified by Lincoln and Guba (1985) and used in this study include credibility, transferability, dependability, and confirmability. The present study utilized a number of techniques to help establish trustworthiness and are outlined below.

Credibility This study employed several techniques to improve the likelihood that the findings and interpretations are credible: prolonged engagement, persistent observation, triangulation, and member checking. In terms of data collection relative to prolonged engagement, data were collected until redundancy of data was achieved and teachers' behaviors were being repeated. Triangulation of data to increase the probability that findings and interpretations were credible was derived from the Contemporary Goals Survey, classroom observations (videotaped and transcribed), collections of written assessments used by the teachers for the students, and semi-structured interviews. A follow-up interview, while providing further data to better understand the teachers' classroom practice, also served as a member-checking procedure. This procedure allowed participants the opportunity to react to our representation of the situation and to clarify uncertainties or inaccuracies.

Transferability According to Lincoln & Guba (1985), "It is … not the naturalist's task to provide an index of transferability; it is his or her responsibility to provide the data base that makes transferability judgments possible on the part of potential appliers" (p.316). The database for the present study contained extensive interactions, documents, interviews, and transcripts that provided the "thick description" one would expect from inductive data analysis and provided evidence by which outcomes of categories and interpretations could be negotiated.

Dependability and Confirmability Both dependability and confirmability were attended to in this study by the use of an audit trail - i.e. a reflexive journal. This technique required the investigator to record information about herself and the study's method. Given the context of the study and the close relationship between participants and the investigator (first author of this study), it was imperative that the investigator continuously be conscientious and aware of the effects of personal values and preconceptions on both data collection and interpretation. The researchers carefully considered how the investigator's presence in the classroom might affect the teachers' behaviors. However, there is evidence that the closer the investigator is to the subject, the greater the possibility of in-depth information being obtained (Stenhouse, 1988). The investigator in this study has been involved with the other science teachers in the school over the past five years as a colleague and critical friend. The professional culture within the school supports reflection and inquiry. Therefore, reactivity may have been less of a threat to the findings of this study. The use of the investigator's reflexive journal, interviews, and member checking, provided the opportunity for examination and clarification of potential threats due to the investigator-participant relationships.

Findings

SHS science teachers strongly emphasized inquiry skills, covering fewer topics in depth, providing a learning environment which broadens and deepens students' responses to aesthetic consideration (beauty of ideas, methods, living organisms, etc.), emphasis on higher order thinking skills, and heterogeneous classrooms. Additionally, SHS science teachers showed preference for the goals of scientific literacy, promoting career awareness in the sciences, stressing the interactions among science, technology and society (STS), science as value laden with moral and ethical dimensions, organizing courses around themes, and experiencing science as a process of extending understanding not as unalterable truth. Also, a strong distinction was shown for knowledge and processes common to all science disciplines over those specific to each discipline, the development of divergent thought processes over the "scientific method," students acquiring new knowledge versus the acquisition of facts, and integration of science, technology, and society over knowledge and processes specific to each discipline. Therefore, in response to research question one (R 1), SHS science teachers consistently showed support for contemporary goals of science education. With respect to research question two (R 2), teachers' strength of conviction to particular goal orientations tended to favor contemporary over past goals; however, some convictions did indicate inconsistencies relative to whether or not STS interactions should be emphasized.

Analysis of moderate and strong emphases responses from the Contemporary Goals survey provided an index for "strength of conviction" (Zeidler & Duffy, 1994). Calculating the weighted mean indicated how strongly those in favor of a particular goal stated their selection (see Table 2). By then comparing the weighted means of goal pairs, the strength of conviction between contemporary and past goals was determined.

Zeidler and Duffy (1994), suggested the use of an index, less than 0.15, to "suggest inconsequential differences in the strength of conviction between contemporary and past goals" (p. 9). Using this same index, only one goal pair (30 - 4), met this criterion (-0.17). Interestingly, while seven teachers stated "no emphasis" on the past goal (#30 - "Science education should focus on knowledge acquisition and process skill unrelated to the interactions of science, technology and society"), one teacher stated "moderate emphasis" and one teacher stated "strong emphasis" thus producing a weighted mean of 2.50. In contrast, contemporary goal #4, (Science education should stress the interactions among science, technology, and society), three teachers stated "strong emphasis", six teachers stated "moderate emphasis" and no teachers stated either "slight emphasis" or "no emphasis", thus producing the weighted mean of 2.33. Therefore, calculating the difference in the weighted means resulted in an index of -0.17.

Pursuing this inconsistency further, findings revealed that one teacher responded "moderate emphasis" to both contrasting goals #30 and #4, while another teacher responded "strong emphasis" to #30 and "moderate emphasis" to #4. These responses, although compelling, do not necessarily articulate the intended goal of the weighted mean as an index for "strength of conviction." In other words, it is difficult to conclude that those who stated a belief in the past goal (#30) do so with the same strength of as that those who stated a belief in the contemporary goal (#4). In fact for one teacher, the strength of conviction

Table 2: Data for Paired Goal Statements

Goal Statement #	Mean	Weighted Mean	Mean Difference	Weighted Mean Difference
31	0.22	0.00		
2	**1.44**	**2.00**	1.22	2.00
16	1.00	2.00		
3	**1.78**	**2.17**	0.78	0.17
29	1.33	3.00		
12	**2.22**	**2.22**	0.89	0.78
30	0.56	2.50		
4	**2.33**	**2.33**	1.77	-0.17
5	0.22	0.00		
23	**2.11**	**3.00**	1.89	3.00
24	0.22	0.00		
9	**1.67**	**2.20**	1.45	2.20
8	0.67	2.00		
21	**2.11**	**2.67**	1.44	0.67
25	0.11	0.00		
17	**2.67**	**2.88**	2.56	2.88
18	1.44	2.00		
11	**2.22**	**2.34**	0.78	0.34
28	0.33	2.00		
19	**2.33**	**2.50**	2.00	0.50
27	0.00	0.00		
15	**2.44**	**2.44**	2.44	0.50
6	0.89	2.00	1.67	0.56
1	**2.56**	**2.56**		
20	1.33	2.00	0.45	0.60
13	**1.78**	**2.60**		
26	0.00	0.00	2.67	2.86
32	**2.67**	**2.86**		
14	1.11	2.00	*	*
10	1.56	2.25		
7	**2.78**	**2.78**	*	*
22	**2.78**	**2.78**		

Note: Contemporary Goals are in **bold** type

* These two goal pairs were not meant for comparison. They were included as validity checks for comparison with prior items.

for each goal (past and contemporary) was the same.

While no other goal pairs fall within the established index of less than 0.15 as outlined by Zeidler and Duffy (1994), one pair was close enough for further investigation. Goal pair #16 and #3 had a difference in weighted means of 0.17. The past goal (#16) states, "The most important knowledge that a science student should have are those facts, concepts, principles, and processes that are specific to each discipline." The contemporary goal (#3) states, "The most important knowledge that a science student should have are those facts, concepts, principles, and processes that are common to all science disciplines." While the group does show preference for the contemporary goal (mean = 1.78 versus the past goal's mean of 1.00), the claim can be made that those stating a belief in the past goals do so with almost the same degree of conviction as those of the contemporary goal (weighted mean of contemporary goal = 2.17, weighted mean of past goal = 2.00).

Except for the two goal pairs addressed above, the science teachers of SHS showed a consistently higher degree of conviction to contemporary goals over past goals. Excluding the two previous goal pairs, the average difference in the weighted means for the pairs was 1.57, with a range of 3.00 to .34, among the remaining twelve paired goals. Overall, the average difference in the weighted means for all the pairs was 1.35, with a range of 3.00 to -0.17.

Research question three (R 3) concerned the consistency between teachers' purported beliefs in contemporary goals and their routine classroom practice and was assessed through focused observations, interviews, and taxonomic analysis of field notes, reflexive journals and video tapes with participants. This process produced 81 codes for classroom practice (too numerous to present in the present article) which were created at the time of the observation. However, it is important to note that the codes and their operational definitions were acquired from the observations and interviews, and were not previously determined. The operational definitions provided the researchers with more specific language or behavior of the teachers, as observed and confirmed by the participants. Once the researchers determined that a thorough understanding of each teacher's routine classroom practice had been reached, there was a need to determine if these classroom practices were associated with any particular contemporary goals of science education. In order to do this, the researchers reviewed all the codes and the contemporary goals as they were stated in the Survey of Contemporary Goals. A category was generated when a code, with its operational definition, showed some relation or connection to a contemporary goal. This produced 30 categories (again too numerous to present here) which directly corresponded to contemporary goals. For example, the category "Authentic Science" was operationalized by the participants as "any comment or behavior relating to 'real life' science; an activity or project, as it would be among the general scientific community" which corresponded to items 1, 2, 13, 19, 22 and 32 on the Contemporary Goals Survey. A second example, the category "Constructivist" was operationalized by the participants as "a comment or behavior which shows evidence of students building new knowledge or a teacher addressing students building new knowledge" which corresponded to item 11 on the Contemporary Goals Survey. Initial judgments were made by the researchers as to whether these categories related to corresponding contemporary goals. Interviews with the teachers were necessary to provide the researchers with a form of verification concerning the connections being made. This member check gave each teacher the opportunity to react to and clarify uncertainties or inaccuracies in the representation of the classroom observations, the categories that were generated, and the corresponding contemporary goals. Selected samples of thought and observations that revealed consistencies or inconsistencies between teacher beliefs and practice based on the operational definitions and category codes are described below. For the sake of brevity, eight samples are described:

1) *Heterogeneity* – There is clear evidence of heterogeneity in this class. Beyond three different grade levels represented, 10, 11, and 12, varying student abilities are apparent. Some students finished the required measurements quickly and went on to sample additional solutions on their own. Teacher B assisted two students who struggled with graphing their data. Many students worked collaboratively and offered assistance to their peers with and without prompting by Teacher B.

2) *Technology* – Various types of technology were used in Teacher B's class, including centimeter sticks, calculators, microscopes, and advanced spectrophotometers. On another day, satellite technology used by the collaborating university generated data for the students' research on remote sensing. In another case, Teacher A expressed frustration over not having technical support to teach the class the way she would have liked: "I could've

done so much more with this lab if I had a computer program with pH probes. We need more instrumentation to get us out to the dark ages. I wouldn't have taught it this way if I had those pH probes."

3) *Higher order thinking* – Teacher C continued to use real life examples as students advanced their understanding of acids and bases. "You're going to have to use some logic to figure out the estimated pH. … This is a logic problem more than anything else. You've got to analyze your data and compare it to this chart to figure out your pH's."

4) *Science process skills, inquiry, and authentic science* – After a week of studying acids and bases, Teacher A used class time to introduce students to their final assessment activity. Students were asked to play the role of a *Consumer Reports* chemist, design an experiment to test which antacid is best, carry out that experiment, and then write an article for the magazine which outlined their process and stated their recommendation for the best antacid. Teacher A: "You will design an experiment to test the neutralizing power of antacid. In doing that, I fully expect that you guys are going into the back room and playing … they (*Consumer Reports* chemists) don't have set tests. They have to come up with their own tests, and that's what you guys are going to have to do. When you are ready to do the write up, look here at these *Consumer Reports* magazines. You'll see how they write their data and summaries of each product. … You are going to have to figure out how much base there is there. It's not an easy thing to do because there are several factors. You decide what concentration of acid to use. Play around with those equations for molarity to figure that out. You'll also need to make your own standard solutions and pick your own indicators. Ask yourself, 'Which one would work best for this concentration?'"

5) *STS* – "This is a hard movie to watch (*Lorenzo's Oil*). Not only is it hard to watch Lorenzo getting sicker, but I found myself getting mad at the doctors and researchers. Remember to think about these two questions (pointing to the white board) while you watch this: 1. How are scientific discoveries made? 2. How is scientific knowledge disseminated?"

6) *Collaboration* – Although Teacher C supports collaboration in her class, she is sure to see that group work doesn't allow for students to <u>not</u> engage. "What, are you guys a group of five now? What I'd really like is for you to *do* the lab, not just watch. Why don't you break up into small groups?"

7) *Affect* – This particular activity produced one consistent response from the students to the sharp color changes as they tested the products with different indicators. Student: "Cool. Boy, those look so cool." Student: "Isn't that cool?" Teacher C: "This is cool. Look at the cabbage one." As the students figured out the pH ranges using the indicators and the chart from the textbook, there were various expressions of celebration, exchanging a "high five" and comments like "Yes, we got each one!"

8) *History* – The class ended with Teacher A further developing the definitions of acids and bases: "I didn't mention this yesterday, but sort of a cool aside. Bromstead was in Sweden

Table 3:
Analysis of Categories Observed and Contemporary Goals Stated

Teacher A

11 contemporary goals stated with a strong emphasis
5 contemporary goals stated with a moderate emphasis

TOTAL = 16 of the 16 contemporary goals were stated with strong to moderate emphasis. Of the 16 goals stated, there was **evidence of 11 categories** which corresponded to the stated contemporary goals, therefore:

Overall Percentage For Teacher A = 65%

Teacher B

7 contemporary goals stated with a strong emphasis*
7 contemporary goals stated with a moderate emphasis

TOTAL = 14 of the 16 contemporary goals were stated with strong to moderate emphasis. Of the 14 goals stated, there was **evidence of 13 categories** which corresponded to the contemporary goals, therefore:

Overall Percentage For Teacher B = 93%

Teacher C

10 contemporary goals stated with a strong emphasis
2 contemporary goals stated with a moderate emphasis

TOTAL = 12 of the 16 contemporary goals were stated with strong to moderate emphasis. Of the 12 goals stated, there was **evidence of 9 categories** which corresponded to the contemporary goals, therefore:

Overall Percentage For Teacher C = 75%

or Norway, up in that area, and Lowry was in England. It was really weird that these two guys published the same theory at the same time having never spoken to each other. And so they're both credited with that."

Clearly, the samples of thought and observations above suggest that while all three teachers varied greatly in their actual practices and the way they expressed their beliefs in their practice, there was a high degree of evidence of teachers' beliefs in the contemporary goals of science education embedded in their routine classroom practice. Table 3 provides further evidence that addresses the main research question to this study: To what extent is a teacher's purported belief in contemporary science education goals embedded in routine classroom practice? The case study evidence for these three teachers indicates that the average number of contemporary goals stated (strong and moderate emphasis) was 14 out of 16 possible statements, while the average number of categories observed as evidence of contemporary goals (derived from the categories derived operationally as described above) through observations of classroom practices was 11. Hence, the average percentage of evidence for categories consistent with stated contemporary goals was 79%, an encouraging indication that the purported beliefs of teachers with respect to contemporary goals were in fact embedded (to a large degree) in their classroom practices.

While this analysis provides interesting evidence of the degree to which these teachers embedded their beliefs in the contemporary goals of science education in their classroom practice, judgments should be reserved. Percentages can be misleading and should not be equated to "good" or "bad" teaching relative to the contemporary goals of science education. For example, given this study's research questions and methodology, a teacher could state a strong belief in one contemporary goal of science education and show evidence in his/her class of that one goal; therefore, the overall percentage would equal 100%. However, in these particular cases, all three of these teachers expressed belief (moderate to strong) in 16, 14, and 12 (respectively) of the 16 contemporary goals.

Summary

This study sought to determine to what extent science teachers' purported belief in contemporary goals of science education was embedded in routine classroom practice. While addressing this issue, the study generated the following grounded research question: What role do authentic science research projects play in a teacher's ability to embed his/her beliefs of science education in routine classroom practice? Authentic science research projects are investigations and lines of inquiry relating to an issue relevant to students' lives which, through research and experimentation, would demand engagement in the knowledge and processes of science (observing, hypothesizing, collecting data, inferring, etc.) and have value or meaning beyond school (Newmann et al., 1995).

All sources of data (observations, interview, and student assessment documents) revealed that, although in different ways, these three teachers' beliefs in the contemporary goals of science education were embedded in their routine classroom practice. Two goals however caused tension for the teachers. Goal #15 - "Science courses should cover a few topics in depth" and goal #23- "Science courses should be offered in a mixed ability (heterogeneous) classroom" were the goals providing the greatest challenge. This was evident in interviews with the teachers. For example, one teacher stated that she has expressed frustration with heterogeneous chemistry classes: "How can you teach chemistry to the whole class if some kids can't even do ratios or solve an equation?" she asks somewhat rhetorically. Teacher C identified deficiencies in mathematics skills as her greatest opposition to heterogeneity: "I think it's great that all kids get exposed to the material, but how can I go fast enough not to bore the bright kids, but slow enough not to lose the kids without strong math skills?"

It would be interesting to pursue this tension further with Teacher C. Are her frustrations about the students' skills, or are her frustrations about her classroom practice? What techniques does Teacher C use in support of heterogeneous classes? Does Teacher C feel confident in utilizing possible strategies to address heterogeneous challenges? Teacher C did, however, share her desire to collaborate with a math teacher to help bridge the gap between the study of math and the applications of math in chemistry classes.

In reference to science courses covering few topics in depth, Teacher A and Teacher C engaged in the following dialogue:

> Teacher A: I honestly believe in the principle, "less is more," but practicing that is still more difficult for me here in many ways. I'm not completely content driven, but I still carry around a certain idea of what I need to cover. I jettison stuff all the time. And with such heterogeneous classes, which I believe in, it's hard to cover all the material

thoroughly for everyone. I've had trouble keeping continuity with our team schedule. It's been really, really hard for me.
Teacher C: … it's very hard to decide what you're going to let slide. I believe in going deeper and not just covering a ton of concepts, but even still, there are basic concepts that are necessary to be able to understand the bigger projects. It's a real struggle.

With the recent publication of national and state standards that claim to also support "less is more," this tension for many teachers may not lessen. In hindsight, the question, "To whom do you feel accountable to cover the content?" may have provided interesting insight as to how teachers decide what material they teach.

Finally, this study, elucidated that reflection on beliefs in the contemporary goals of science education and classroom practice raised the teachers' awareness of both what they do and what they do not do. This was evident in comments such as the following:

Teacher A: You know what will be interesting?
Investigator: What?
Teacher A: Seeing if I don't contradict myself in the classroom, because I struggle with that.
Investigator: Can you say more about that?
Teacher A: Yeah, I just feel like I'm not doing what I'd really like to be doing. I feel comfortable with my beliefs about what I should be doing as a science teacher, [but] I know that I'm not doing all that I'd like to be doing. My beliefs are still evident, but there's so much more I'd like the students to be engaged in. That's where the projects would come in. Projects could get at a lot of the things I haven't done this year.
Teacher B: … you know, sometimes I do have a sense of myself, sometimes. I think about what I'm doing. But, sometimes I just get up and do what I do and then the next class comes in, and I do it again. But working with you (the investigator) is neat. It's really neat. I've never thought hard about what I do and why I do it. It's been so good for me to talk to you.

By engaging in this process of inquiry together, collegial relationships were deeply enhanced and analytical reflection cultivated providing teachers with the necessary foundation for making changes in their classroom practice.

Allowing this study's methodology to emerge from the interactions between investigator, participant, the data collections and analyses, provided the researchers the opportunity to develop a generative research question from the data. The grounded research question that emerged was: *What role do authentic science research projects play in a teacher's ability to embed his/her beliefs of science education in routine classroom practice?*

Implications and Recommendations for Future Research

This study provided the teachers with a safe and supportive environment to discuss, reflect, and analyze teaching practices and goals of science education. The value and need for this type of reflection and collaboration is documented in the literature of professional development and school reform (Anderson, 1992; Battista, 1994; Cronin, 1991; Fullan, 1993). While an increase in awareness was evident, and valuable, it is interesting to wonder if this awareness will continue to provide enough motivation to cause significant change in educational practices. The participants in this study have capitalized on opportunities for learning. Since the completion of this study, participants have initiated further discussions with the investigator seeking support for their desire to change and improve their classroom practices.

Similarly, the literature suggests that research on education improvement needs to involve teachers in ways which respect and engage their ideas, interpretations, observations and analytical strategies (Anderson, 1992; Battista, 1994; Cronin, 1991; Fullan, 1993). Respect for a teacher's expertise as a vital component to educational change is consistent with the approach championed by Fullan (1993): "Educators must see themselves and be seen as experts in the dynamics of change" (p. 4). The relationship between the investigator and the three participants in this case study was based on a sense of shared expertise, respect, and trust. By engaging in this process of inquiry together, collegial relationships were deeply enhanced and analytical reflection cultivated providing teachers with the necessary foundation for making changes in their classroom practice.

Among the recent trends in science education, authors have stressed the importance of building collaboration among teachers and providing opportunities to critically analyze their own work and ideas (Motz, 1997; Rhoton, Madrazo, Motz & Walton, 1999.) Rather than simply being subjects of the present research, these teachers were participants in the inquiry. Therefore, while addressing the primary research question, this study not only adds to the knowledge within the science education research community, but it indirectly benefited the participants in their pursuit of effective science education. While schools across the nation are struggling with issues of reform, this investigation provides the field of science education with a case study of a school that is actively engaged in the recommendations for improved science education, therefore acting as a model for other schools grappling with the challenges of change.

The insights gained through this research provided a rich understanding of the degree to which these teachers' purported beliefs in science education are embedded in their routine classroom practice. It should be noted that the present study is consistent with carefully examining the pedagogical dimensions of phenomenological research programs called for by Erickson (2000). The specific context and focus of this initial inquiry leaves open the same questions for much larger populations and in other settings. Other questions raised through this inquiry that may provide fertile ground for further research, include:

1) If a teacher's purported beliefs in the contemporary goals of science education are not embedded in his/her routine classroom practice, does awareness of this dissonance initiate change in classroom practice, and beliefs?

2) Does an increase in the awareness of a teacher's beliefs in the contemporary goals of science education and his/her classroom practice provide sufficient motivation for change? What are the other necessary supporting components to sustain improvements in classroom practice?

3) To what degree do preservice science teachers' believe in the contemporary goals of science education and how would the preservice teachers describe routine classroom practice supportive of these beliefs?

4) What role does the school's philosophy and/or mission play in science teachers' beliefs in the contemporary goals of science education?

5) How can research of this nature incorporate students' perspectives of their science education relative to their teachers' classroom practice?

These are all questions grounded in the results of this inquiry. As the education research community continues to construct meaning, generate theory, and participate in the process of change, research of this kind not only helps to inform that body of knowledge, but also suggests guiding questions for future inquiries. Continued research studies such as this one, which cultivate teachers' thinking about their beliefs and their classroom practice, will help support the quest for understanding the process of educational change in science education.

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