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TEACHERS' VIEWS AND PRACTICE OF REFORM GOALS IN SCIENCE EDUCATION

By

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ABSTRACT

TEACHERS' VIEWS AND PRACTICE OF REFORM GOALS IN SCIENCE EDUCATION

By

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Teachers' views and practice of reform goals, and changes in them as they taught with curriculum materials designed to exemplify those goals, were investigated to document the effects of using new curriculum materials as an approach to the reform of science education. These changes were studied through interviews with six upper elementary teachers before and after they used the materials, and through observations of their teaching.

The reform goals are those currently advocated by the American Association for the Advancement of Science (Project 2061), the National Research Council's Science Education Standards, and Michigan's Essential Goals and Objectives for Science Education. They are: (1) Promote understanding over content coverage; (2) promote learning that is useful and relevant outside of the classroom; (3) promote scientific literacy for *all* students; (4) promote interdisciplinary learning.

The study created a conceptual framework, an elaborated description of the reform goals as presented in national, state and research documents, with contrasting sets of positions as analyzed from the teachers' interview comments and observed teaching and in the literature. These positions clustered into three specific orientations, the "scientific literacy focus," the "discipline-based focus," and the "traditional focus."

Teachers were found to have varying positions on the goals both before and after teaching, but almost all manifested important changes toward the scientific literacy focus after using the materials. Changes included new commitments to reducing content coverage, making complex subjects simple for students, connecting teaching to real-world phenomena, and using strategies that promote increased interaction between teacher and student. Several teachers recognized that typically low-achieving students could reach high levels of understanding through effective teaching.

Changes were not seen, however, on one aspect of the reform goals: the ability of scientifically literate people to *use* knowledge in real world settings. Recommendations were made regarding increasing the effectiveness of using curriculum materials for reform, both as a means for providing teachers with knowledge needed to teach effectively, and within the larger context of systemic reform.

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CHAPTER 1: OVERVIEW

Science education in elementary and secondary schools is changing, however slowly. Reformers are advancing new notions about the aims of science education, based on the need of all citizens to understand science in ways that will help them make personal and community decisions and be competent in emerging technology-driven workplaces.

Different approaches have been taken by reformers. Incentives for changing practice are proposed; sanctions against schools that don't change are threatened. Broad policies are mandated that are intended to have effects on school structure and governance, the education and selection of teachers, and the core curriculum of schools, and to hold schools more accountable for student achievement. Reform efforts are also proposed that intend to support teachers in changing daily practice. These involve development of the profession and of the individual practitioners through opportunities to gain knowledge on which new practices can be built, as well as the provision of new curriculum materials and other classroom resources.

The development of new curriculum materials is one approach to reform that has a long history. It has been seen as a potentially strong way to encourage change in practice, because curriculum materials relate directly to the classroom activities of students and teachers. While the use of newly designed curriculum materials is typically optional, it is precisely that characteristic that makes this approach to reform more palatable to many in the education system, and therefore potentially more lasting.

Research on the use of curriculum materials in promoting new approaches to practice is therefore critical to an understanding of how teachers change. The research reported here concerns the role of curriculum materials in the reform of science education. Its purpose was to determine changes in teachers' positions regarding the reform of science education as they worked with teaching materials designed specifically to exemplify reform goals. It intends to be a contribution to the research traditions that study teachers' knowledge and beliefs, and how they are changed.

In particular, the study was an evaluation of one specific unit, *Hard As Ice* (Michigan Department of Education, MDE, 1994a),[1] created to exemplify the reform goal of scientific literacy for all students—as it affected the knowledge, attitudes, teaching strategies and learning goals of six mid-Michigan upper elementary teachers.

The study analyzed comments made by the teachers in interviews held before and after they taught with the unit, looking for indications of their positions on reform of curriculum and teaching. It also analyzed their teaching of three of the unit's lessons, again looking for indications of their positions on reform as revealed in their classroom practice. In order to be specific about the nature of science education reform and the positions held by teachers on reform, the study created a conceptual framework—an elaborated description of the reform goals, as presented in national and state documents, with contrasting sets of positions as seen in the teachers' comments and teaching and in the literature.

This report presents the findings of this study. Along with the conceptual framework, the findings include a description of the positions of the study's

[1] The unit is part of a series created between 1990 and 1995 by a team of teachers and curriculum developers at the Michigan Department of Education.

six teachers on reform goals, and an analysis of the changes seen in their positions over the course of using the unit. This report considers the implications of these findings for continuing curriculum development activities and other reform initiatives.

Background and rationale for the study

Efforts to reform science education in K-12 schools are underway throughout the United States. Local school districts, colleges and universities, state departments of education, national non-profit organizations, and the federal government are all endeavoring to reshape the form and substance of science teaching, through curriculum revision, teacher education, school restructuring, and new assessment practices.

People and organizations throughout Michigan have been participating in, and sometimes leading, various reform initiatives. The Michigan Department of Education has recently developed new Essential Goals and Objectives for K–12 Science Education (Michigan State Board of Education, MSBE, 1991) based on *Science for All Americans*, the report on scientific literacy of Project 2061, the national science education reform effort of the American Association for the Advancement of Science (Rutherford & Ahlgren, 1989). The Michigan Goals and Objectives present an extensive set of objectives at 4th, 7th and 10th grades, intended to lead reform of the science curriculum in public schools.

These objectives are premised on a definition of scientific literacy that encompasses the broad goals of:

1) promoting deep and connected understanding of scientific ideas rather than broad coverage of topics;

2) promoting learning that is useful and relevant outside of school, not just within narrowly-defined, traditional school contexts such as laboratory exercises and standardized achievement tests;
3) promoting scientific literacy for all students, including those who are not necessarily going into technical or scientific careers and those from groups that have been traditionally underrepresented in science courses and scientific careers (women and most U. S. minority groups); and
4) promoting appropriate interdisciplinary learning that connects science fields (such as chemistry and biology) and that uses language, mathematics, and social studies as skills and contexts for learning science (MSBE, 1991, pp. 3-4).

The objectives are also the basis for the development of a revised state all-pupil assessment in science at grades 5 and 8 (MDE, 1994b), and a high school proficiency assessment that determines state endorsement of students' diplomas. Because of this required assessment program, schools throughout the state are interested in the objectives on which the tests are based, and are therefore involved with the scientific literacy reform movement.

The developers of the new Michigan goals and objectives understood that reform of science education does not occur simply by producing new objectives, providing incentives to local districts to use them in some highly general way, and holding students accountable for learning the objectives. The developers recognized that a fifth "goal" needs to be the development of support systems for teachers.[2] These support systems should include new

[2] This goal was not listed with the four others in order to list only this reform effort's conception of scientific literacy. It is listed, nevertheless, in MEGOSE along with the other four.

professional development, new collegial relationships in schools, financial, administrative and parental support, and new teaching materials. To provide new teaching materials and workshops to help teachers learn to use them, MDE has established a long-term project to develop model teaching units correlated with the new state objectives.[3] These new materials and workshops are intended to help teachers see how the objectives can be drawn together into integrated curriculum materials that exemplify the goals listed above. The researcher is director of this project, titled the Michigan Science Education Resources Project. His work encompasses several science education reform efforts, both ones that produce policy documents (the objectives and the MEAP science assessment) and ones that are primarily educative in nature (professional development, materials development).

MDE has, therefore, a four-pronged approach to reforming science education in the state: (1) the state goals and objectives, which specify what students need to know and be able to do to be scientifically literate; (2) newly designed teaching materials, which embody the goals and objectives and provide valuable instructional resources to Michigan teachers and students; (3) professional development activities geared to helping teachers understand what it means to be scientifically literate and how to develop a local curriculum that supports reform; and (4) a state-wide assessment that will show (to the extent possible with state-wide tests) the degree to which students are accomplishing the goals and objectives.

At the federal level, the National Research Council is creating standards for curriculum, teaching, and assessment in science education that compliment the Benchmarks for Scientific Literacy (American Association for

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[3] This project is funded by the W. K. Kellogg Foundation; the teaching materials are referred to as *New Directions* Science Teaching Units.

the Advancement of Science, 1993) developed from *Science for All Americans* (Rutherford & Ahlgren, 1989); the National Science Foundation is considering the development of curriculum materials based on new national standards as a strategy for promoting reform. Other strategies for promoting reform are debated across the country, not just ones that provide new knowledge for teachers, but ones that are directed toward incentives and sanctions. Given this, knowledge about the influence of teaching materials on teachers' understanding of and practice within the guidelines of reform standards is important. New knowledge about how Michigan's specific reform efforts reach out into the education system and interact with and influence practice could be very helpful to both state and national long-term reform efforts.

Specific research questions

This study's contribution to knowledge about reform initiatives is specifically related to the role of curriculum materials in bringing about reform: how teachers view the reforms represented by the materials; how they enact the materials (including what they choose not to enact, and why); and how their positions on reform, and their practices, change through use of the new teaching materials.

Four specific research questions were addressed:

1) What positions do teachers take on state and national reform goals for science education (specifically those listed on pp. 2-3), and how do these positions change as they use new teaching materials developed to embody those goals?
2) What kinds of practices occur in teachers' classrooms as they use the new teaching materials?

3) How are those practices similar to or different from ones intended by the developers of the materials (intended to embody the reform goals), and how do the teachers view those deviations, especially in terms of their positions on the reform goals?
4) How are those practices similar to or different from the teachers' prior practices (as reported by the teachers), and how do teachers account for any changes in their practice?

Overview of the research design

To answer these questions, this study had to develop conceptual and methodological tools for determining and articulating positions on reform goals. The conceptual framework developed in the study defined the range of teachers' positions on reform goals and provided detail within each goal. The methodology used allowed the researcher to probe teachers' positions on reform in clinical interviews, and to look for information in their teaching related to their positions on reform.

The study took place within a larger pilot testing of the *New Directions* unit *Hard As Ice*. The unit is about liquid water, solid ice, and molecules. It was designed specifically to conform to the goals for reform: It reduced content coverage to focus on helping students understand key ideas; it attempted to make the content useful and relevant for students when they are out in the world, not just in the classroom; it was designed to help *all* students reach significant levels of scientific literacy in this area; and it made use of interdisciplinary connections.

Fifth and sixth grade teachers were recruited to pilot test the unit. They taught it in the spring of 1995. They provided constructive feedback for revising the unit. They also agreed to be interviewed about their science teaching and their positions on reform issues to help the developers understand how the unit might be used and how successful it might be with teachers who hold various approaches to teaching science.

They were interviewed individually, before and after teaching with the unit. The interview methodology was based on the clinical interview approach. Teachers were asked questions relating to their approaches to teaching science, what they want to accomplish, what they thought about textbooks and their curriculum, etc., from which their thinking about the reform goals could be inferred. The post-teaching interview also asked them about specific aspects of the unit, as a focus for discussing the reform goals it was designed to embody.

They also allowed their teaching of three lessons from the unit to be observed, and their students' learning to be assessed at the end of the unit, on a test constructed by the unit developers. Field notes were taken during the classroom observations that recorded what the teacher and students said and did.

New conceptual and methodological approaches had to be developed to analyze the classroom observation and interview data in ways that would determine teachers' positions on the reform goals. The conceptual framework for the study—which elaborates on and provides contrasts to the reform goals—was developed in response to this challenge, as were the methods for deducing teachers' positions from the data. The methods will be explained in detail in Chapter 3, and the conceptual framework in Chapter 4.

Limitations of the research design

Several limitations arose in the research design as the study progressed. The first was the small number of teachers in the study. Originally nine teachers had agreed to pilot the unit, but only six eventually did pilot the unit in such a way that their teaching could be used in the research[4]. Of those six, only five agreed to have their teaching observed, and two of those teachers taught only two of the three lessons designated to be observed.

Two of the teachers did not teach the first section of the unit, lessons one through five. They started with the lessons that were going to be observed, the sixth, seventh, and eighth. This did not give them the same experience with the approaches and strategies used in the unit as it did those who taught the entire unit (although they did not hold back on commenting on the unit's pros and cons). None of the teachers taught lessons nine through 11, because they were all teaching late in the spring and felt time pressures to move on to other science priorities.

A third limitation was the fact that the teachers were using a pilot version of the teaching materials. Whether this would become a severe limitation depended on the problems that the pilot teachers identified with the unit, that is, the aspects of lessons that needed to be substantially revised. Fortunately, the teachers had great praise for the pilot version, making suggestions for relatively small changes that would make the activities proceed more smoothly, or for a small amount of additional background information. On the whole, the teachers said that they learned all they needed to teach the unit from the information already in the pilot version, and felt that their students learned what they wanted them to learn from it.

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[4] One decided not to teach the unit because her student teacher had done something similar earlier in the year; one taught the unit before contacting the researcher to set up the pre-teaching interview and classroom observations; the third scheduled surgery during the spring and left the teaching of the unit to her intern, who decided not to teach the section containing the lessons that were to be observed.

There is also a limitation inherent in the clinical interview approach used in the research. The interview generally asks questions that are based on some concrete aspect of teaching or the unit, and therefore indirectly related to the goals. The questions are designed to elicit teachers' thoughts and beliefs about the goals, although it was not always the case for every goal, even with questions that tend to elicit responses from other teachers. How this silence is interpreted depends on other statements the teacher has made. But in some cases the interviews did not provide information on one or two goals for a few teachers. Ideally, additional interviews would be conducted to probe teachers' positions where no information was obtained in the first interview. Unfortunately, due to other demands on the researcher's and teachers' time, this did not happen.

The structure of this report

Chapter 2 sets this study in a theoretical framework, and describes the research literature on which this study draws. A portion of the chapter is devoted to elaborating on the reform goals, in ways that provided the depth needed to inquire into teachers' positions. Research studies with similar intentions, and that have provided theoretical perspectives or conceptual guidance, as well as methodological tools, are discussed.

Chapter 3 presents the methodology used to assess teachers' positions on the goals. It will be seen in this chapter how the methodology required and led to the development of the conceptual framework, as well as the empirical results.

Chapter 4 presents those results. It is divided into four sections that present: (1) the conceptual framework for describing teachers' positions on the goals, as developed in this research; (2) the actual positions of teachers in the study and changes in their positions as they used the unit; (3) the value of the methodology for conducting this study, and (4) what the study shows about the reform goals themselves.

Chapter 5 summarizes the study, discusses what the results mean, and suggests what implications there may be for reform activities and further research.

CHAPTER 2: THEORETICAL FRAMEWORK AND RELATED RESEARCH

This research is based on a number of assumptions and theoretical perspectives. Chief among them is that the current reform of science education, which promotes scientific literacy for all students, is a worthwhile aspiration and important path for science educators to follow (Rutherford & Ahlgren, 1989; Michigan State Board of Education, 1991). What scientific literacy means, and how it may be pursued in classrooms, is described in the first section of this chapter.

This research draws on several theoretical perspectives about teaching and learning as well. Those perspectives are a part of the research tradition that provides the backbone and the impetus for this study. That tradition concerns the teaching and learning of specific science topics (Smith, 1985). Those perspectives will be discussed in the second section of this chapter.

This research tradition draws on eclectic methodology, which is discussed briefly in this chapter as a prelude to Chapter 3.

Scientific literacy

Central to Michigan's reform is the conceptualization of scientific literacy from Project 2061 of the American Association for the Advancement of Science and the Michigan Essential Goals and Objectives for Science Education (MEGOSE). Project 2061 has written (Rutherford & Ahlgren, 1989) that scientific literacy has six basic dimensions:

- Being familiar with the natural world and recognizing both its diversity and its unity;
- Understanding key concepts and principles of science;
- Being aware of some of the important ways in which science, mathematics, and technology depend upon one another;
- Knowing that science, mathematics, and technology are human enterprises and knowing what that implies about their strengths and limitations;
- Having a capacity for scientific ways of thinking;
- Using scientific knowledge and ways of thinking for individual and social purposes.

This is a highly complex view of what *all* Americans need to know about and be able to do in order to be scientifically literate. Yet it brings onto the agenda for science education several aspects of science that are not normally taught in schools, and it downplays aspects of science that have traditionally had considerable attention in the curriculum. It highlights the connections among science, mathematics, and technology; the limitations of the scientific enterprise; and the need to be able to *use* scientific knowledge and ways of thinking for important and real purposes (as opposed to purposes having to do with school-work). Their report states that

> The treatment of [science] topics tends to differ from the traditional in two ways.
>
> One difference is that boundaries between traditional subject-matter categories are softened and connections are emphasized. Transformations of energy, for example, occur in physical, biological, and technological systems, and evolutionary change appears in stars, organisms, and societies.
>
> A second difference is that the amount of detail that students are expected to retain is considerably less than in traditional science, mathematics, and technology courses. Ideas and thinking skills are emphasized at the expense of specialized vocabulary and memorized

procedures. Sets of ideas are chosen that not only make some satisfying sense at a simple level but also provide a lasting foundation for learning more. Details are treated as a means of enhancing, not guaranteeing, understanding of a general idea. The council believes, for example, that basic scientific literacy implies knowing that the chief function of living cells is assembling protein molecules according to instructions coded in DNA molecules, but does not imply knowing the terms "ribosome" or "deoxyribonucleic acid," or knowing what messenger RNA is and how it relates to DNA.

> The national council's recommendations include some topics that are not common in school curricula. Among these topics are the nature of the scientific enterprise, including how science, mathematics, and technology relate to one another and to the social system in general. The council also calls for some knowledge of the most important episodes in the history of science and technology, and of the major conceptual themes that run through almost all scientific thinking. (Rutherford & Ahlgren, 1989, pp. 4-5)

Drawing on the work of Project 2061, the Michigan Department of Education commissioned an effort to develop goals and objectives for science education in the state, on which local districts could build strong K-10 science programs.[1] This effort was also predicated on the need for all students in the state to have a substantial education in science that would prepare them for the challenges of a highly technological workplace and for community and personal decision-making where science plays a role. The Michigan Essential Goals and Objectives for Science Education (Michigan State Board of Education, [MSBE], 1991) state:

> The scientific enterprise in our society is vast, complex, constantly developing, and powerful. Scientific knowledge enables us to describe and explain the natural world with a level of precision and insight that previous generations could hardly imagine. Science also contributes to our technological and economic development, giving us a capacity to change the world around us. Because science is so complex, no individual

[1] Decisions about the curriculum for 11th and 12th grades were left to the local districts. It was the intention of the advisory panel that developed the Michigan Essential Goals and Objectives for Science Education to revisit high school science at some point in the future, to develop objectives or guidelines for "advanced" high school science, but that has not happened to this point in time.

> can hope to understand it all. Some knowledge of science is essential, however, for full participation in the economic, political, and cultural functions of our society. The primary purpose of K-12 science education, therefore, must be *scientific literacy*—an understanding of those aspects of science that are essential for full participation in a democratic society—for *all students.*
>
> A commitment to the goal of scientific literacy for all students means that "covering content" is not the most important goal of science education. More important, Michigan students should come to understand science as a living, vibrant, important way of looking at the world and to use scientific knowledge successfully in their work, in their leisure time, and in fulfilling their duties as citizens. (MSBE, 1991, p. 3)

These words set the stage for the reform of science education across Michigan. The foundation for this reform was established in a set of four reform goals.

The goals for the reform of science education in Michigan. Given that scientific literacy is the overarching direction toward which science education is moving, the goals for the reform of science education, described below in the language of MEGOSE, are pillars on which science curriculum and teaching can be redefined. They are:

1. Emphasize understanding over content coverage.

> Science teachers and curriculum developers have responded to the increasing size of the scientific knowledge base by trying to cover more and more science content in the same amount of class time. Recent research on science teaching and learning provides clear evidence that this strategy is failing; most students are memorizing facts rather than becoming scientifically literate.
>
> The objectives have been written in a way that attempts to reduce content coverage and emphasize depth of understanding. This document contains 212 objectives, or fewer than one for every two weeks of science teaching throughout the K-12 school program. Further, many facts and terms found in middle and high school science textbooks are left out. For example, terms such as *ribosome, villi, voltage, acceleration, bromine, basalt*, and *Coriolis force* are not in this document. At the same time, detail has been provided about what it means to understand the terms and ideas included in the objectives, as well as understand some of the qualities that make those ideas challenging for students. As they reexamine their science curricula, teachers and curriculum committees

> should consider whether they may be sacrificing depth of understanding for breadth of content coverage. (MSBE, 1991, p. 3-4)

When students understand deeply, they are able to reason with their knowledge about real events and phenomena. They are able to use scientific knowledge to describe the world around them, to explain how things work and why things happen, to make predictions about events yet to happen, and to design systems using scientific principles. Their understanding is of how the world works, not of isolated abstract theoretical bits of information, and their knowledge of key concepts and principles allows them to understand and/or figure out about parts of the world they are not familiar with. They are able to show and work with the connections inherent in their knowledge. They can construct new knowledge, by posing questions, conducting appropriate inquiries, drawing conclusions from data, and communicating what they have learned to others. They are able to reflect on the nature of scientific claims, the evidence and logic used to support them, the analogies and themes they draw on, and their historical and social contexts.

To develop deep understanding, students need to be given opportunities to investigate important questions, to work with materials, to struggle with evidence and alternatives, to articulate their thinking, and to pose their own questions. The amount of factual detail and number of topics in the curriculum must be reduced to allow time for this. Teachers must practice a kind of strategic teaching: They must choose carefully the key questions, problems, and inquiries that allow opportunities for deep thinking, a kind of deep thinking that challenges students' naive conceptions. Teachers need to scaffold students' developing understanding and create a learning community in the classroom.

This kind of teaching is not easy. It requires that teachers have strong content knowledge. In addition, it requires that teachers have subject-specific pedagogical knowledge to undergird strategic teaching: knowledge about how the subject should be represented for students at a particular age, the activities, analogies, problems, questions, etc. that will help students learn the subject deeply, not superficially (Shulman, 1986).

And it requires that teachers have knowledge of students' developing understanding. This includes knowledge of the conceptual development going on in each student in their class, as well as the ways students typically go wrong in learning specific topics. This knowledge must be gained on an on-going basis through interactions with students or their work.

2. Emphasize learning that is useful and relevant outside of school.

> Vocabulary-based approaches to science teaching are sometimes rationalized with the claim that "basic facts" must be learned before students can engage in the "higher order thinking" required by in-depth activities. There is now a large body of research-based knowledge that supports the belief that the "facts-first" approach to science teaching is practically and developmentally inappropriate. Even young students ask many questions about the world and have developed many strategies for finding answers to their questions. Thus, most students engage in activities requiring "higher order thinking" **before** they learn "basic scientific facts."
>
> The objectives promote science learning that makes connections with the world outside of school by emphasizing **activities** learners engage in and **contexts** they will encounter outside of school. As they reexamine their science curricula, teachers and curriculum committees will need to consider how, and how well, they are connecting the knowledge and experience that students acquire outside of school with the classroom activities that occur in school. (MSBE, 1991, p. 4)

This goal insists that abstract, theoretical knowledge of science is not sufficient for scientific literacy. Instead, students need to learn science in ways that make connections to the real-world. They need to be involved in the kinds of activities that scientifically literate people do outside of school:

diagnosing problem, explaining and describing phenomena, applying knowledge, predicting and testing predictions, designing and constructing technological things, reflecting on the merits of arguments, questioning, communicating, making connections, making decisions based on limited information, etc.

To make this happen, all aspects of curriculum and instruction need to be embedded in real-world phenomena, systems, and events. The curriculum needs to address problems, applications, and connections, whether they are mundane (such as why a flashlight doesn't work, or societal, such as what we should do with low-level radioactive waste). Students need to be allowed to draw on their everyday experiences with these contexts, and reflect on the validity and consequences of their everyday theories about them.

3. Emphasize scientific literacy for *all* students.

> The lives of all students are influenced by knowledge from the sciences and its application, and all students need to understand science if they are to fulfill their duties as citizens and their potential as individuals. The widespread evidence of scientific illiteracy among students and adults, as well as the alarming underrepresentation of minority and female students in science, indicate that many students are not well served by existing science programs.
>
> The objectives support the development of programs that serve all students by emphasizing knowledge that is useful to all, and by providing information about how people of all races and cultures have contributed to science (see Appendix A). As they reexamine their science curricula, teachers and curriculum committees will need to promote strategies that serve all students. (MSBE, 1991, p. 4)

It is a logical conclusion of the premises of scientific literacy that *all* students must become scientifically literate. The challenge for education is to reach out to those students (the majority) who have been alienated from science, who view science as something that happens in school but is not really the way the world works, or who have been told that "science is not for you." The challenge is to find the appropriate encouragement, opportunities, and instruction to bring those students back to science.

4. Promote interdisciplinary learning.

> Teaching that involves students in complex activities in real-world situations is necessarily interdisciplinary in nature. Scientifically literate people must also be literate in the traditional sense. For instance, they must read expository text with comprehension and speak and write coherently. Some science objectives require the use of mathematical knowledge in measurement or problem solving. Others require understanding relationships among science, technology, and society. To achieve these objectives, students will have to use scientific knowledge in combination with other kinds of knowledge about the world; their success will depend on science teaching that emphasizes connections.
>
> The objectives support interdisciplinary learning by emphasizing activities that connect science and technology with learning of other subjects, and by emphasizing conceptual and thematic connections among the objectives (see Appendix B). As they reexamine their science curricula, teachers and curriculum committees will need to consider how they will help their students see connections among the sciences and between science and other school subjects. (MSBE, 1991, p. 4)

The important problems that scientifically literate people need to deal with can be solved only by bringing together ideas from several disciplines. The problem of why the flashlight doesn't work may involve the chemistry of batteries as well as the physics of circuits and conductors. The problem of the disposal of low-level radioactive waste may involve the diverse fields that produce it, such as medicine and manufacturing, as well as the physics of radioactivity and the geology and/or materials science of storage solutions.

These examples also show the need for skills and knowledge from outside of the science disciplines. Scientific and technological problems are often intertwined with economics and politics; mathematics is often used to express and solve some aspects of these problems; and expressive skills are needed to clearly articulate the problem and present possible solutions.

Perspectives on reform goals from outside of science education. Many of the themes developed above are echoed in research and reform initiatives outside of science education. These lend weight to the arguments for scientific literacy and show the strength of this "movement" beyond science. A comprehensive review of this literature is not included in this dissertation, but two exemplars are discussed here.

Brophy (1992), in a review of the literature pertaining to the teaching and learning of specific subjects, draws out several key recommendations made across these studies that are in agreement with the ideas about scientific literacy described above. He compiled a set of "principles of good subject matter teaching," which address curriculum and assessment as well as instruction. Many of these principles are contained in the goals for scientific literacy and the elaboration under each, described above.

> Principles of Good Subject Matter Teaching
>
> Although research on teaching school subjects for understanding and higher-order applications is still in its infancy, it already has produced successful experimental programs in most subjects. Even more encouraging, analyses of these programs have identified principles and practices that are common to most if not all of them (Anderson, 1989; Brophy, 1989; Prawat, 1989). These common elements are:
>
> 1. The curriculum is designed to equip students with knowledge, skills, values, and dispositions useful both inside and outside of school.
> 2. Instructional goals underscore developing student expertise within an application context and with emphasis on conceptual understanding and self-regulated use of skills.
> 3. The curriculum balances breadth with depth by addressing limited content but developing this content sufficiently to foster understanding.
> 4. The content is organized around a limited set of powerful ideas (key understandings and principles).
> 5. The teacher's role is not just to present information but also to scaffold and respond to students' learning.
> 6. The students' role is not just to absorb or copy but to actively make sense and construct meaning.
> 7. Activities and assignments feature authentic tasks that call for problem solving or critical thinking, not just memory or reproduction.

8. Higher-order thinking skills are not taught as a separate skills curriculum. Instead, they are developed in the process of teaching subject-matter knowledge within application contexts that call for students to relate what they are learning to their lives outside of school by thinking critically or creatively about it or by using it to solve problems or make decisions.

9. The teacher creates a social environment in the classroom that could be described as a learning community where dialogue promotes understanding. (Brophy, 1992, p. 5)

As can be seen from this list, the ideas inherent in the scientific literacy reform movement are consistent with principles for effective teaching and curriculum approaches generated by research across the subject matter areas.

Another line of synthesis is from Newmann and Wehlage (1993). They attempt to define five "standards" for authentic instruction, based on three criteria consistent with the school restructuring movement: that students construct meaning and produce knowledge, that students use disciplined inquiry to construct meaning, and that students aim their work toward production of discourse, products, and performances that have value or meaning beyond success in school. These five standards are:

1. Higher-order thinking. This "requires students to manipulate information and ideas in ways that transform their meaning and implications, such as when students combine facts and ideas in order to synthesize, generalize, explain, hypothesize, or arrive at some conclusion or interpretation. Manipulating information and ideas through these processes allows students to solve problems and discover new (for them) meanings and understandings" (p. 9).

2. Depth of knowledge. Knowledge concerns the central ideas of a topic or discipline. Students have deep knowledge "when they make clear distinctions, develop arguments, solve problems, construct explanations, and otherwise work with relatively complex understanding" (p. 9).

3. Connectedness to the world beyond the classroom. What is learned must have value and meaning beyond the instructional context. Students should learn to apply knowledge in personal and social contexts.

4. Substantive conversation. Students and teacher have considerable verbal interaction about the ideas of the subject. Students explain themselves, ask questions, teachers respond to their ideas and questions, and participants generally build on what others have said to promote improved collective understanding of the subject.

5. Social support for student achievement. There is an environment in the classroom which provides "high expectations, respect, and inclusion of all students in the learning process" (p. 10).

As can be seen from these "standards" and "principles," there is considerable agreement across the research and reform communities on what constitutes appropriate curricular and instructional focus, when the aim of school is to develop students' deep and useful understanding. These additional expressions of important approaches to teaching and learning were useful in this study in conjunction with the goals for scientific literacy.

Research traditions

Three research traditions form the foundation for this study. They include research on the teaching and learning of specific subjects, research on teacher thinking, planning, and decision-making, and research on policy and practice.

Research on the teaching and learning of specific subjects: Conceptual change. Across the subject areas, specific research attention has been paid to how the disciplines are conceptualized so they can best be learned in school, what teachers know about the subjects they teach, how students learn subject matter, etc. In science, this research tradition has studied the planning and teaching of science (e.g. Smith & Anderson, 1983; Anderson & Smith, 1987), the beliefs of teachers about science learning and their role in it (e.g. Hollon, 1987), the effects of curriculum materials on teaching (e.g. Smith & Anderson, 1983, 1987), the conceptual understanding of students in specific topics (Hesse & Anderson, 1992), and the role of various instructional strategies in changing students' naive conceptions (e.g. Smith, Blakeslee & Anderson, 1993). A strong theoretical base of this research on science education is that learning takes place as a process of conceptual change (Smith, 1991; Posner, Strike, Hewson, & Gertzog, 1982; Carey, 1986).

Research on teacher thinking. A larger research tradition to which conceptual change has many connections is the tradition on teacher thinking, planning, and decision-making. This tradition has studied teachers' planning, the decisions teachers make when they are in the middle of teaching, and the implicit theories they hold about teaching (Clark & Peterson, 1986). It has shown that teachers typically are scanning their teaching environment for information about their practice, processing it as well as possible given the sheer magnitude of the information available, and making many instructional decisions based on that information. It has shown that the complexity of teaching and the teaching environment make it impossible for teachers to always make decisions rationally to guide every step of their instruction, so they rely on routines and established practice to make their teaching manageable. This is in keeping with cognitive psychology, which has explained the nature of human perception and action—in areas where considerable information is present in the environment—as the process of constructing simplified cognitive models of the actual event and acting rationally within those simplifications. In other words, humans are "boundedly rational" (Simon, 1957).

Research on policy and teaching practice. A third research tradition to which this study is connected concerns the influence of policy and programs on the practice of teaching. This is a crucial research perspective for this study because the context of this study is the reform of science teaching, and reform efforts are often manifested in state and federal mandates or other types of policies or programs that are intended to steer the education system (or some aspect of it) toward the reform goals, either through incentives or sanctions. As described earlier, the state of Michigan has a four-pronged approach toward the reform of K-12 science education, each prong representing some type of policy or program with some degree of loose or tight controls.

This line of research has looked at the effects of policies on practice, and developed explanations to account for why the education system is not as easily controlled by policy and federal or state programs as those who conceive them would like. It has drawn on work from the other social sciences which shows that "street-level bureaucrats" like police officers, social workers, and teachers, have considerable latitude in their actions, even though they are governed by policies and employed by bureaucracies, because of their relative independence in their daily actions and their resulting isolation from strong external controls (Lipsky, 1980). This is why it is possible for teachers' practice to look so different even when they are working under the same framework of policies and reform programs (Cohen, Peterson, Wilson, Ball, Putnam, Prawat, Heaton, Remillard, & Wiemers, 1990). The conclusions of this line of research have generally been that the effects of educational policies and programs depend mostly on what teachers make of the policies and programs (Elmore & McLaughlin, 1988), primarily classroom teaching is loosely coupled to school authority. The thrust of broad reform efforts today is toward systemic implementation (Smith & O'Day, 1991) which attempts to align the curricular, instructional, assessment, and structural reform efforts to provide one coherent message to teachers about the direction of reform.

Assumptions about teaching and learning derived from the research traditions

Two important assumptions undergird this research, as they do the research traditions described above:

Learning is a matter of conceptual change. Learning for understanding involves sometimes difficult changes in one's conceptual knowledge. Teaching has to make that possible.

Learners have complex knowledge structures (ideas about the world and competencies in it) that are used for learning new knowledge, but their existing knowledge structures can interfere with learning in cases where what they know is at odds with what they are trying to learn; this is "the problem of conceptual change" (Toulmin, 1972; Carey, 1986). This problem is especially perplexing when students are asked to bring their knowledge to bear in explaining how something in the real world works, that is, when they are asked to put their "theories in action" (Driver & Erickson, 1983).

Posner, Strike, Hewson & Gertzog (1982) describe a process of conceptual change that is parallel to the paradigm shifts of the science disciplines: Learners become dissatisfied with an existing idea; they must see alternatives to the idea that are intelligible and plausible; and they must come to view the alternative as more fruitful than the existing idea for describing, explaining, making predictions, etc. (See also Smith, 1991; see Strike & Posner, 1992, for a re-examination of some aspects of their theory.)

For teaching to be helpful to learners, it must present new ideas in ways that address students' naive conceptions, providing a base of relevant experiences that challenge the students' naive conceptions (create dissatisfaction) and helping the students see the usefulness (intelligibility, plausibility, and fruitfulness) of the new ideas (Anderson & Smith, 1986; Anderson, 1989; Anderson & Roth 1989; Hesse, 1990; Smith, Blakeslee, & Anderson, 1993; Prawat, 1989). Smith (1991) argues that for conceptual change to occur in educational settings, students must be engaged in processes where they draw on their own knowledge, reason and argue with it, draw inferences and conclusions and test them against experience. This helps convince them of the plausibility and value of thinking about the world in new and sometimes counterintuitive ways.

Teachers are primarily rational when making decisions about their practice. Since this study looks closely at the decisions teachers make having to do with instruction and their reasons for those decisions, it is necessary to describe the theoretical perspectives of this study related to how teachers' make complex choices.

The assumption of this study is that teachers make instructional decisions rationally, being guided by their ethical responsibility to students, within political, technical, and professional environments that exert outside influences; given that to some extent they are conditioned by deeply-held conceptions of learning and culturally-determined orientations toward teaching. The explication of the reform goals, above, and alternatives to the reform goals found in this and other studies, are based on this assumption: They do not contain images of teachers as technicians, following lock-step approaches to their work, or as making irrational decisions based on subjective preferences or emotional pressures, but rather show how teachers can take a range of professionally sound positions on reform. See Shulman and Carey (1984) for an elaboration on this position.

This assumption contains a view of the process of changing one's orientations toward teaching which has several components: (1) Given the caveat stated above—that humans are "boundedly rational" when acting on information perceived in their environment—teachers make decisions based on feedback from their teaching activities (such as assessment data, information volunteered from students, their own reflection on the effectiveness of their lessons) and review that information almost constantly (Clark & Peterson, 1986); (2) Teachers make decisions based on outside pressures—the demands of their clients (parents and students) and their bosses (principals, other administrators, school boards)—in an arena where external controls are weak; teachers become policy-brokers whose actions are seen as essentially rational responses to micro-political situations (Schwille, Porter, Belli, Floden, Freeman, Knappen, Kuhs, & Schmidt, 1983); they also respond to professional norms—another type of external pressure (such as when their profession calls for new approaches to curriculum); and (3) Teachers hold assumptions about students, learning, and the goals of education that influence their teaching without being especially explicit (Lortie, 1975), and these are changed only by becoming cognizant of them and their consequences, seeing alternatives and the possible fruitful application of alternatives, and receiving feedback from making a change that indicates the greater usefulness of one orientation over another. In this sense teacher change is probably similar to the changes students go through in learning new conceptual material (the conceptual change research tradition), which is more thoughtful than behavioral.

Each of these aspects of change is important for viewing the effects of new teaching materials on the teachers in this study. The research expects that teachers use new teaching materials in rational ways that are conditioned by norms of the profession, their own deeply held beliefs, and the expectations they perceive to be held by their bosses and clients. This research does not try to account for which factors contribute most to the teachers' decisions, but will rather be cognizant of the fact that this assumption means that change is generally hard for most people, although teachers are able to put forward reasons to explain their actions and beliefs.

<u>Learning challenging subject matter occurs best when the entire education system is directed toward that end</u>. The science education reform effort in Michigan is a four-pronged effort, as noted in Chapter 1. It includes curriculum standards, teaching materials based on the standards, assessment based on the standards, and professional development designed to help teachers understand and practice within the reform goals. This is in keeping with systemic approaches to reform, particularly the approach advocated by Smith and O'Day (1991), who propose that the power of state education policy is increased when all of the components of the state education system are aligned and therefore coherent in the messages they send about reform.

The four elements of Michigan's science education reform efforts listed above are key to persuading, leading and supporting teachers, students, and other stakeholders to change practices. However, there are additional aspects of the "system" that also need attention: teacher education, for one; the role of parents and the community, for another; other laws and regulations governing education, and so on. While these elements were not addressed in

Michigan's initial efforts to reform science education, they have since been included in a more global effort[2] that encompasses the original four elements. The slogan of this more global effort is the African phrase that "it takes a village to raise a child," which recognizes that developing scientific literacy will take more than just pronouncements of reform and sanctions for not improving achievement test scores.

Specific related research

Three studies are especially important as background for this study, both for their conceptualization, and for their methodology. Each is described briefly below.

Precursor to this study: Research on the effects of science curriculum materials on teaching. The research described in this dissertation draws heavily for its conceptualization and research methodology from earlier research on the effects of science curriculum materials on teaching and planning (Smith & Anderson, 1983; Smith & Sendelbach, 1982; Hollon, Anderson, & Smith, 1980; Landis, Smith, & Anderson, 1981; Smith & Anderson, 1987). One of these reports will be discussed in detail here.

Smith & Anderson (1983) describes a study that looked in detail at teachers' use of curriculum materials. Specifically, the researchers wanted to understand patterns in teachers' use of elementary curriculum materials during planning and teaching, including the reasons for those patterns and their effects on instruction and student learning. They also wanted to understand the effects of an intervention based on the earlier analyses and designed to help teachers use the curriculum materials more effectively. The

[2] This effort is funded by the National Science Foundation, as part of its statewide systemic initiatives program.

intervention was primarily the use by teachers (in a second phase of the study) of a revised teachers guide that took into account and tried to compensate for some of the patterns observed in the first phase.

The first phase of the study was a naturalistic inquiry into how teachers planned and taught using a commercially available program, one designed to promote effective science teaching and learning. The intent of the researchers in this phase was to see how the materials were used by "real teachers" and to compare their use with what the program developers had intended.

To do this, the researchers analyzed the literal program of the curriculum materials (following methodology developed in an earlier study by Landis, Smith & Anderson, 1981). The literal program analysis provided a structure for looking at teachers' planning and instruction with the curriculum materials. The literal program consisted of a listing of "features" or steps of the curriculum materials that the teacher would follow if she or he taught exactly as the materials instructed.

Along with the listing of features of the literal program, the researchers listed the function of each of the features. The function represents the developers' intentions in designing each feature and sequencing them as they did. For example, the first feature of the literal program was "Discuss a plant's needs for light to grow." Its function was listed as "Establish issue, bring out student ideas." All together there were 19 features of the curriculum materials being studied, which required approximately 17 days of instruction.

The researchers also interviewed teachers about their planning, observed their classroom instruction (following methodology developed in an earlier study by Hollon, Anderson & Smith, 1980), and assessed and described students' conceptual understanding of the topics addressed by the materials (following methodology developed in an earlier studies of student's conceptions, including Roth, Smith & Anderson, 1980). They used the teacher interviews and classroom observations, together with the teachers' plan books, to ascertain the extent to which the literal program had been followed.

The researchers found a large influence of the curriculum materials on actual instruction. Over 60 percent of the teachers incorporated all but two features of the program in their teaching. Nevertheless, many of the features were modified in such a way that they deviated from the intent of the developers. These modifications were primarily of literal program features that involved discussion, while the features that involved carrying out experiments were almost always done without modification. The student tests showed that most students ended the instruction without understanding the essential conceptions about plants that the instruction was designed to teach them.

The researchers saw in the patterns of modifications several overarching approaches to teaching science. While the materials had been developed essentially from a conceptual change perspective, teachers who were not familiar with that approach could not easily see it in the curriculum materials and practiced teaching in ways that they were perhaps more accustomed to. The two most prevalent patterns were the "didactic-knowledge acquisition view" and the "discovery-knowledge development view." In both views, the students' preconceptions played no role; learning was not viewed as a change in one's thinking brought about by new experiences. Rather, it was viewed as simply the addition of new knowledge to what one already knows.

In the didactic view, learning involves the acquisition of knowledge presented by the teacher (or, by extension, in the text). The teacher shaped this acquisition process by developing a coherent story line that weaves together explanation and examples to help the students learn the content.

In the discovery view, learning involves the development or "discovery" of knowledge by students who are conducting investigations. The teacher sets up the investigations and helps guide the students through them when necessary by posing the "research" questions, teaching them how to observe carefully and make measurements, and holding them to the data when they draw conclusions from it. This approach attends more to the students' observations and interpretations of them, and less to the degree to which they may support existing naive preconceptions. The discovery view of teaching is more sophisticated than the "activity-driven" perspective found in earlier research by Smith & Sendelbach (1982), where teachers felt that students would learn what they needed simply by conducting the investigations (or reading the text); the discovery view has more active involvement by the teacher in some elements of the teaching situation. Nevertheless, all three of these approaches fail to confront students' naive ideas, and therefore fail to help them gain a clear understanding of the science behind the investigation or contained in the story-line.

The researchers also found that the curriculum materials themselves were not especially well-suited for providing teachers the kinds of directions needed for teaching as the developers intended. They argued that the large amount of varied kinds of information presented in the curriculum materials overtaxed the teachers' abilities to process the information completely, and so the teachers relied on well-established personal routines for processing the curriculum materials as they planned, which contributed to deviations in the actual teaching from the intended curriculum. (The researchers have argued subsequently that teachers need certain kinds of knowledge for effective teaching, much of which can and should be supplied by curriculum materials; see the discussion below regarding Anderson & Smith, 1987.)

In phase two of the study, the researchers redesigned the curriculum materials to make the conceptual change perspective more explicit, reduce the demands on teachers to process large amounts of information, and show how each of the activities contributes to the overall teaching plan of the unit. They did not revise the literal program, believing that the activities and discussions should be adequate for teaching the ideas of the topic. In phase three, a new group of teachers used the newly-designed curriculum materials, and had varied degrees of success. The researchers attribute this to problems inherent in the literal program.

In their discussion of the study, the researchers argue for an approach to understanding the role of curriculum materials in effective teaching that is based on an integrated research and development cycle. Such a cycle would examine how teachers make use of the materials and how their practice is influenced by them; re-design the materials to take this information into account; and investigate how the revised version is used and its effects on student learning. The literal program analysis approach, coupled with classroom observations and interviews with teachers, would be used in this type of research and development to provide a depth of knowledge about the effects of teaching materials that is not available presently.

<u>Another important research base: Teachers' conceptions of learning and teaching</u>. Hollon (1987) conducted a study that follows in this teacher thinking/conceptual change tradition, using interview and classroom observation methodology to determine teachers' beliefs about the nature of learning and their associated approaches to teaching. The interviews

provided information about teachers' knowledge of the subject matter, their goals for student learning, their understanding of what their students knew, and the resources and strategies teachers considered most important for promoting learning.

From the interviews and observations, he identified three different orientations toward teaching and learning, which to some extent echo the perspectives discussed in the previous study. The first was the "conceptual development" orientation. Teachers who held it viewed learning as a process of changing one's ideas when they are seen as naive and when more fruitful ideas are understood; they adopted curricular goals which focused on students' meaningful understanding of a few important concepts; and they monitored students' thinking during instruction to help them change their thinking. This is a conceptual change orientation.

The second was the "content understanding" orientation. Teachers in this category viewed learning as the addition of knowledge to what students already know; they focused their curriculum on an integrated body of knowledge; and believed that it was their task to communicate that knowledge clearly and monitor students' understanding of important details of it.

The third orientation was labeled "fact acquisition." The learning emphasis was on memorization of facts, the curricular goals were determined by the instructional materials being used, and the emphasis in teaching was on managing activities (along with certain social goals).

The orientations toward learning and teaching in the studies by Smith and Anderson and Hollon—along with the goals for scientific literacy and standards and principles described earlier in this chapter—were drawn on to develop a conceptual framework for this investigation (described in Chapter

4), which was used to account for the various positions taken by the teachers in this study. The research methodology used in this investigation is derived from those studies as well, with modifications as demanded by the nature of this investigation's research questions.

Knowledge teachers need to teach for conceptual change. Flowing through the two research studies reported above is the notion that effective teaching facilitates a process of conceptual change in individuals, similar to the kind of change that occurs in scientific fields when one paradigm replaces another (Posner, Strike, Hewson & Gertzog, 1982; Smith, 1991; Strike & Posner, 1992). Anderson and Smith (1987) have argued that to make conceptual change happen in classrooms, teachers need two kinds of knowledge: An overarching perspective on conceptual change, and topic-specific knowledge. The overarching perspective is one where teachers have the disposition to elicit student thinking and search for barriers to developing understanding. Topic-specific knowledge includes deep understanding of the key ideas of the topic, typical student naive conceptions, and appropriate pedagogical content knowledge (Shulman, 1986). This pedagogical knowledge includes the key questions of the topic that effectively engage students in discussion; phenomena that challenge students' naive conceptions ("discrepant events"); analogies and examples that clarify the scientific conceptions, etc.

Anderson and Smith suggest that curriculum materials can provide a major portion of this knowledge. In their research—which studies the use of curriculum materials—teachers have typically learned a great deal of the content knowledge involved in the topics when the curriculum materials were written to explicate that knowledge rather than to just tell it in a fashion that does not discriminate between facts and larger conceptual schemes in the topic (concepts, principles, laws, theories). When materials explicitly discussed the naive conceptions that students have, and provided specific activities whose goal was to address those naive conceptions and help students see the problems with them, teachers gained knowledge about students. And when the materials were developed specifically to provide a framework for strategic teaching, teachers gained the pedagogical knowledge represented by the materials' procedures. This argument will be drawn on in Chapter 5 of this report, where the implications of this present study will be elaborated.

Research on policy and practice in mathematics education. One important difference between the investigation being reported in this dissertation and the Hollon study described above is that, while teachers in both were pilot testing new teaching materials, the Hollon study did not look at changes in teachers' beliefs about learning as a result of their experiences with the new materials.

A research study that did look at changes that took place in instruction as teachers grappled with new instructional goals and methods was a study of California's reform effort in mathematics education (Cohen, Peterson, Wilson, Ball, Putnam, Prawat, Heaton, Remillard, & Wiemers, 1990). This research focused on the issues of what teaching mathematics for understanding entails, which was at the center of reform efforts in California, and what policy can do to promote teaching for understanding. At the heart of the study was the actual classroom practice of 23 teachers, and the changes they went through as they encountered and worked with California's state Mathematics Framework and textbooks that had been recently revised to reflect the new framework.

The researchers interviewed teachers about their understanding of the Framework and what they thought it implied for teaching, curriculum, assessment and learning. They tried to ascertain the demands of the Framework from the teachers' points of view, as well as the resources teachers felt they needed to practice within the policy prescriptions. They looked closely at the topics taught by the teachers and the specific content within the topics, as well as the topics that teachers chose *not* to teach. They examined their pedagogy and classroom organization, and inquired into how their present teaching may differ from how they have taught in the past.

To do this, classroom observations were made over three days, two towards the beginning of the study and one several months later, when the teachers had supposedly more experience with the Framework. Observation notes were made, as well as audiotapes; shortly after class ended, observers identified the major "chunks" of the lesson and the teacher's use of textbook, manipulatives, and cooperative groups. Also, observers wrote responses to analytic questions on an observation guide shortly after observing the lesson. These questions helped the observers describe the content and approaches taken in the lesson more completely.

A post-teaching interview was conducted that probed the teachers reasons for selecting the content and using the pedagogical approaches observed in the lessons, and probed what they thought their students learned. Using all of these data sources, the researchers wrote case studies of the teachers.

As seen across all of the cases, the researchers believed that the instructional policy made a difference in teaching, although those differences varied from teacher to teacher. They accounted for these differences by arguing that the teachers in the study interpreted the policy differently, and therefore enacted it in a variety of ways. One of their cases is about a woman who does not know much mathematics, but who embraces new activities and wants math to be fun. Another is about a man who teaches long division as an algorithm, even though his textbook provides a context for division that allows students to think about its meaning. His students score high on the state assessment, primarily in the "procedural" section, which is fine with him: He believes that learning has to progress from procedural to conceptual, and that only the brightest students can learn conceptually. Neither of his beliefs are espoused by the Framework.

The researchers spoke directly about the role of textbooks in reform, since most of the teachers' contact with the policy came through textbooks that were revised specifically to convey the policy. They found that teachers generally adapted the text, rather than teaching its literal program directly as written. One adaptation involved skipping entire topics that seemed developmentally inappropriate, even though those topics were an integral part of the reform. Another adaptation involved modifying certain activities, which often subverted the intentions of the developers. But the researchers also saw teachers learning both new mathematics and new pedagogy from trying new activities suggested by the texts. One teacher "confessed that he learned something from the experience: He never had imagined that his fifth graders could think and reason in such advanced ways. It seemed to him that if he could continue to have such experiences, his teaching might change more fundamentally" (p. 162).

This research, and the two other pieces described above, provide important context, questions, and methods for the study described in this dissertation.

Summary of Chapter 2

The theoretical foundations for this study include commitments to learning as a process of conceptual change, teaching as primarily a rational activity, and reform as effective only when systemic. The research traditions in which this study resides include research on the planning and teaching of specific science topics, teachers' thinking, and the effects of policy on practice. The emphasis of the reform movement in which this study is embedded is scientific literacy, an approach to understanding and using science in the real world.

The research methodology used in this study was shown to be derived from methodologies used in similar studies within the research tradition, with appropriate refinements as necessary to inquire into new research questions.

CHAPTER 3: METHODOLOGY

While several different approaches were available for collecting data about teachers' beliefs and classroom teaching, the research traditions discussed in Chapter 2 provided the approaches used to collect the needed data. The conceptual change research tradition is very interested in drawing out students; underlying conceptions of the phenomena of the world, and from it the clinical interview approach was chosen for collecting information from teachers about the conceptions that underlie their approaches to curriculum and teaching—their positions on reform issues. This approach is in contrast to a survey research approach which might ask teachers directly if they favor one reform position over another. Asking direct questions such as "Would you prefer a curriculum that promotes understanding or a curriculum that covers a great deal of content?" would, more than likely, elicit a preference from elementary teachers for the reform position.[1] The clinical interview approach allows teachers to talk more about their practice and their thoughts concerning many curriculum and teaching issues.

The method used to collect data from classroom observations is closely aligned with the fieldwork research tradition, where the actions and speech of the teacher and students is recorded fairly verbatim, providing a rich

[1] This is not to single out elementary teachers pejoratively; it is simply the experience of the researcher that simple questions elicit simple answers, and also that—for this particular question—the non-reform position is most often taken by secondary teachers who are willing to make a case for a curriculum that de-emphasizes understanding in order to expose students to many topics in the sciences.

description of classroom activity from which categories and assertions about teaching may emerge. This was necessary for the development of the conceptual framework. The method of using field notes was blended with the methodology used in Smith & Anderson (1983) that compared the expected teaching program to the actual teaching program, as a guide for looking at the enacted curriculum.

The details of the methodology are described below.

Participants in the study

Nine teachers volunteered to pilot test the *New Directions* teaching unit *Hard As Ice*, and share their thoughts on different aspects of teaching science. Two left the study before the first interview, and a third taught portions of the unit before the interviews and classroom observations were scheduled, effectively removing her from the study. Of the six that remained, two taught K-5 science in a mid-sized urban school district (they used the unit with their fifth grade classes), three taught fifth grade in a suburban district, and one taught sixth grade in a suburban district. Two of the fifth grade teachers and the sixth grade teacher had two classes of science. Four were women and two were men; they ranged in classroom teaching experience from five years to "very many."

Four of the teachers taught most of the unit (Lessons 1 through 8, but not 9, 10 or 11) and the other two taught only Lessons 6, 7, and 8. Although they volunteered to teach the unit before the winter break, all waited until May to begin, which is why they did not teach the last three lessons of the unit.

Two of the teachers described themselves as having attended many workshops given by the university in their region or by their intermediate school district. One participated on a state-level committee that wrote items for the state's all-pupil assessment. Two who worked in the same district used a textbook extensively, while three created their own units (rarely drawing on the textbook), and one used units developed by his district. All said that they liked teaching science, and all said that they had very little background in the physical science content of this unit.

Pseudonyms are used throughout the report.

The instructional unit

Hard As Ice (Michigan Department of Education, 1993) is a fifth or sixth grade unit designed to help students construct a clear understanding of the solid and liquid states of matter and what happens when solids melt into liquids or liquids freeze into solids. It was also designed to help student learn to pose questions, search for solutions to problems, work together with others, and value the need for evidence in making decisions.

As can be seen from the table of contents (Table 1), *Hard As Ice* is primarily about water, in its liquid and solid states. As the unit progresses, students learn how to explain the essential difference between ice and water—that you can stick your finger through water, but not through ice—in terms of the motion and arrangement of molecules. The unit is set in the context of the water all around us, including lakes, rivers, ice on ponds, and snow on fields.

The unit contains 11 lessons, each one or two class periods long. Lessons 6 though 8, which were the observed lessons, deal with the most difficult content in the unit, on the structure of solids and liquids and the processes of melting and freezing. A detailed description of Lessons 6 though 8 is in the appendix, referred to as the "literal program."

The unit is one of seven units developed to provide resources to teachers in Michigan that are based on the state's Essential Goals and Objectives. The

Table 1
Table of Contents for *Hard As Ice*

Lesson 1	**Letter to Phoenix Describing Michigan** Students write a letter to a fictitious student in Phoenix describing what Michigan is like, including our water environment.
Lesson 2	**Describing Water** Students concentrate on improving their descriptions of water.
Lesson 3	**What Makes a Good Description?** Students look carefully at several forms of water in the classroom, describing them using categories.
Lesson 4	**Revising Letters to Megan** Students revise their original letters, utilizing their improved descriptions.
Lesson 5	**How Do People Adapt to the Water in Their Environment?** Students extend their study of the water environment to include social and economic uses of the hydrosphere.
Lesson 6	**Why Is Ice Hard?** Students consider the essential difference between ice and liquid water, and how it can be explained in terms of molecules.
Lesson 7	**Making Ice** Student make ice, and construct an explanation of what happens when water freezes.
Lesson 8	**Which Weighs More?** Students are challenged to consider whether a puddle of water weighs something different from the ice cube that melted to form it.
Lesson 9	**What Else Melts?** Students melt other substances and explain what's happening in terms of molecules.
Lesson 10	**What Else Freezes?** Students freeze other substances and explain what's happening in terms of molecules.
Lesson 11	**What About Snow?** Students extend their understanding of solids and liquids, melting and freezing to figure out whether snow is a solid or something else.

units are intended to give teachers a picture of what teaching for scientific literacy might entail. To accomplish that, each was designed to specifically address the four reform goals. *Hard As Ice* addresses the goals in the following ways (as taken directly from the unit introduction, pp. 1-2):[2]

> *1) Understanding over content coverage.* To be scientifically literate, students need to have a deep and connected understanding of the big ideas of science. In this unit those ideas include 1) differences in the characteristics of substances can point to differences of the underlying structure of substances; 2) all substances have an underlying structure that are made up of extremely small particles that are in constant motion; 3) the motion and arrangement of those extremely small particles determines whether the substance is a solid or a liquid; 4) heating up a substances increases the motion of its molecules to a point where they can break apart from the rigid array they are in as a solid and move freely past each other, becoming a liquid.
>
> This kind of conceptual understanding takes time. That's why these units are relatively long. For some teachers, the commitment of six to eight weeks for one unit in science seems like a sacrifice of other important content. But to really understand the "big ideas," students need to see how scientific concepts like "molecules" connect to the real world of substances melting and freezing (or solidifying). And they need to see how the concepts they learn make sense to them in terms of ideas they're already familiar with, whether they have to do with ice cubes in the freezer or bodies of water in the hydrosphere. This kind of learning is fundamentally different from science teaching that skims across many topics, often overwhelming students with new vocabulary.
>
> *2) Learning that is useful and relevant outside of school.* Scientific literacy means an understanding of science that can be put to good use outside of school. For that reason, we have chosen topics for the *New Directions* teaching materials that connect scientific ideas, skills, and habits of mind with important "real-world" systems, events, and problems. In this unit, for example, molecules are studied in the context of water freezing into ice on the top of a pond, or icicles melting into drops of water.
>
> But "science outside of the classroom" can run into difficulties, especially when students have naive ideas, or misconceptions, about how the world works. In this unit, for example, students often confuse

[2] This introduction was written by the researcher, in his role as author and project director for development of the units.

the macroscopic physical appearances of solid substances such as ice with the nature of the underlying structure, believing that if there is any underlying structure to ice, it must be composed of things that are "hard," "icy," or "frozen" (and similarly that the molecules of water must be "liquidy" or "slippery" or "wavy"). It is only when they come to understand the power of the molecular theory of matter for explaining how things melt and how thing freeze, that they are willing to give up their naive ideas about what those molecules must be like. Because these ideas have proven to be relatively difficult for students in these grades, we have chosen to focus primarily on water in its solid and liquid states—and not other substances—as a context for learning these important ideas.

One of the important goals of these new materials is to connect students' developing scientific ideas with the ideas they already use to make sense of the world. Sometimes this involves relatively little change in the ways they think; sometimes it involves "mind-bending" change.

3) Scientific literacy for all *students.* Scientific literacy includes the ability to use scientific ideas, to understand the world around us, to construct new ideas by asking questions and searching for answers, and to reflect on the adequacy of explanations and solutions. In this unit students learn how to use the idea that all matter is composed of molecules to explain melting and freezing as they see it all around them in their environment. They learn how to describe different forms of water in the hydrosphere (such as lakes, rivers, snow fields, and ice flows) in a level of detail that gives them clues to the deeper molecular structure of ice and liquid water. They learn to apply the molecular theory of matter — which states that all matter is composed of extremely tiny particles that are constantly in motion — to everyday examples of solid and liquid water melting and freezing. As students learn about the world around them, they sharpen their abilities to ask questions and construct answers. They have opportunities to design investigations, and interpret the results of their investigations, and to reflect on the evidence needed to support their arguments and decisions.

Scientific literacy is not just for those who show an early interest in science or those who might pursue related careers. It is for *all* students. Because fewer and fewer young women and minority students develop an interest in science and technology, these *New Directions* units incorporate materials and approaches to support and encourage them in succeeding and staying in science. The units also utilize approaches that are often successful with mainstreamed students.

4) Interdisciplinary teaching. The world is interdisciplinary. Chemistry alone or physical science alone or technology alone doesn't provide answers to important social questions. And students shouldn't see the world as compartmentalized, with language arts occurring between 9 a.m. and 10 a.m., mathematics between 10 a.m. and 11 a.m., and science only after lunch.

These units draw from as many scientific disciplines as necessary to dig deeply into the topic. In this unit, physical science and technology are closely woven together. The unit also provides multiple opportunities for strengthening students' language arts abilities.

The unit was created from a conceptual change perspective (Anderson and Smith, 1987). That is, the unit gave teachers strategies for eliciting student thinking and responding to it, and provided student activities and background information for teachers that addressed typical student naive conceptions of the subject matter. The developers used a "teaching/learning cycle" to make decisions about sequence of activities.[3]

Directions to the participating teachers

Teachers in the study understood that they were pilot testing the unit, and for that reason should look carefully in their planning at every step of the procedure. They were told, though, that they could modify the "literal program" (the exact directions that constitute the procedure for each lesson) as they saw fit, to enhance it or "fix" anything they felt might not work. They were not given any directions relating to the background information in the unit, or any of the introductory remarks (nine pages of theoretical and practical information concerning the unit, including explicit discussion of the four goals and how they apply to the unit).

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[3] The teaching/learning cycle used in the development of the units is a blend of approaches to curriculum development that includes the contributions from the long line of "learning cycle" proponents as well as contributions from theorists concerned with conceptual change and cognitive apprenticeship approaches to learning. The cycle used by the developers was one where the class is first engaged with a problem or question, they explore the problem and their theories about potential solutions, they construct potential solutions based on information gathered in the "exploration" stage and with the guidance and use of the theoretical resources of the teacher (that is, the teacher explains things when they are needed for constructing the solution), then the solution is tested in various new contexts and new questions are generated.

Procedures for collecting and analyzing interview data, including development of the conceptual framework

Conducting the interviews. Interviews were conducted with each teacher, both before and after using the unit, to probe into teachers' positions on the goals. They followed a clinical interview approach, where questions were posed concerning some aspect of teaching, learning, or the curriculum which elicited responses from teachers that contained information about their positions on the goals. The interview did not directly ask teachers to state their beliefs regarding each goal, because of the difficulty of articulating a theoretical position with very little preparation, nor did it ask them to choose from among several positions the one that they mostly closely identified with (as a telephone survey of political leanings might); instead, it asked questions about the teachers' typical approaches to science teaching, what they considered to be important for students to learn, what they liked and disliked in the unit and what they might change, what they think teachers might learn from using this unit, etc. A copy of the interview questions is in the appendix. Additional questions were added to several post-teaching interviews to inquire into specific aspects of individual's teaching or to gain information on that individual's positions that might have been missing from the pre-teaching interview.

First analysis: No predetermined categories. Each interview was transcribed from audiotape. It was then read carefully and broken into segments, where each segment represented a single topic—an answer to a question, or comments on a single issue—and placed into a computer data base, one segment per record.[4] The segments varied in length from one paragraph to one page.

[4] "FileMaker Pro" was used to store and code the interviews.

After being placed on the computer, each segment was read again, and notes were written in a data base field next to the segment. These notes summarized the teachers' comments related to their positions on the Goals. One or two category labels were then added to each record, to represent the general topic of that segment. These category labels were not predetermined, but came from several taxonomies of teaching and curriculum available in the general literature, such as "activities," "content knowledge," "goal of unit," "group work," "processes of science," "knowledge of students," "prior knowledge," "success as a teacher," "interdisciplinary," "understanding," "molecular explanation," "group work," "student activity," "problem-solving."[5]

Development of the conceptual framework. While the interviews were being conducted, the researcher was searching for ways of describing the goals that would adequately show the detail and fine distinctions in them, yet would be expressed in a simple format that would be useful in the analysis. As a beginning, the category labels that were first applied to the interview segments (shown above) were sorted by the goals and listed as different facets of each. These listings became subcategories under each goal. These subcategories helped explicate each goal. As an example from the first draft of this explication, under Goal 1 "Promoting understanding over content coverage" were the subcategories of *making decisions about the curriculum; making decisions about teaching strategies, approaches, or techniques; learning about the content;* and *learning about students.* The subcategories provided a finer-grained conceptual analysis of the Goals. They are used for

[5] This list does not include all of the categories.

explaining the goals in Chapter 2, even though the subcategories were developed as the study progressed.

The interview data also provided contrasts to the goal positions. For example, one teacher suggested that the district curriculum should be followed even if it meant "skimming the top" of the topics they dealt with. Many described their efforts to teach about conducting inquiry in science in ways that indicated that inquiry was disconnected from the content of the course. Some argued that the primary connection between science class and the outside world took place during field trips (as opposed to routinely having real-world contexts as a part of science).

These contrasts also drew on analyses from the literature on teaching in science and other fields (references in Chapter 4 where each set of contrasts is explained). The contrasts were added to the descriptions of the goals and their subcategories, to produce the conceptual framework (presented in Chapter 4).

Using the conceptual framework with the interview data: second analysis. The interview segments were then re-read and re-coded,[6] using the conceptual framework. As teachers' comments in the interviews were coded with an appropriate subcategory, a short note was written next to the code which indicated their position on this subcategory in language taken relatively directly from the interview, rather than from the goal subcategories.

To judge the objectivity of this coding process, a second person familiar with the reform goals but unconnected to this research coded a sample of 24 data base records (15% of the total data base), after being trained in the approach used for coding. Between the two coders there were 40 codes

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[6] On a different layout of the data base that hid the original comments.

marked on the 24 records. Her codings were then compared to the researcher's codings. 85% of the time the two coders chose the same passages in the interview segments to code, indicating that there was excellent agreement between the two on what information in an interview segment contained pertinent information. 73% of the time the two coders chose the same code, or subcategory. These figures were satisfactory to the researcher, so that no adjustments in the approach to coding the interviews had to be made. (The second coder did notice one aspect of one interview segment that the researcher missed; it was added to the information compiled for that teacher, but did not affect the final results for that teacher.)

Coding the first four interviews was extremely difficult and time-consuming, as the framework was being developed simultaneously with insight gained from the interview analysis. Coding interviews became considerably easier after the conceptual framework was developed, so much so that the coding provided some empirical justification for the conceptual framework: It seemed to adequately represent diverse and specific teaching positions. As the framework fell into place, the ease and speed of coding the interviews greatly improved.

Compiling comments by goal subcategory. These codes and notes were then compiled into tables for each teacher. A sample from one teacher, Mrs. Vandenberg, on one goal subcategory, is shown in Table 2. In the "before" column, a single code and note was found relating to the goal subcategory shown (an oddity—usually there were at least two notes per cell). A short narrative attempts to synthesize her position, using evidence from the note and, when necessary, re-reading the interview. In the "after" column, five code and note entries are included that relate to this goal subcategory. Again, a short narrative attempts to synthesize her post-teaching interview position.

Table 2
Sample Analysis Form for Compiling Interview Codings

	before	after	changes?
1: l'ing goals	1: l'ing goals (kind of k: processes need to be taught and used; content is easier for students to learn; both need to be done together; processes are an essential element of science) **before**: Strong emphasis on method as a learning goal (but not with direct reference to the constructing objectives); speaking from her experience, she notes that "the content will come" (perhaps because her teaching strategies make that happen). "I think the process needs to be there because that's a part of critical thinking, they need to know how to go about solving a problem, the content, you know, they'll get the content... If you do just content and leave out the process then you're really not teaching them science."	1: l'ing goal (change misconceptions/develop understanding) 1: l'ing goal (other: social responsibility; listening and showing respect) 1: l'ing goal (understanding; coverage needs to be reduced) 1: l'ing goal (other: reflecting on what they've learned) 1: l'ing goal (content to be learned — reflecting; she is confusing metacognition with the "reflecting" objectives) **after**: More explicit discussion about teaching for understanding of content — addressing misconceptions, reducing coverage. Nothing mentioned about "processes of science" (although the unit uses them—but perhaps not in the way she envisions—didn't she recognize the constructing objectives in use in the unit? Or didn't she apply them herself in teaching the unit, during the inquiries?—check cls obs. Also, she uses the term "reflecting" in her own way).	She talks more specifically, more explicitly about "understanding" in the post-int., but her other responses in the pre-int. indicate she is committed to "understanding" as a l'ing goal. (See 1: str's; 1: k abt ss; 2: r-w contexts) (Nothing about "processes" mentioned in the post-int., does this indicate a strong conceptual orientation of the unit?) **change**: along the process-to-content continuum, from process side of center to content side of center. No specific change from coverage to understanding: Her conception of learning "processes" is that it should be learned as it is used, not learned out of context in a memorized way (as "these are the steps in the scientific method. We'll have a test on Friday.") That is, she seemed to say in her pre-int. that processes should be *understood*.

In the "changes?" column, an initial analysis is written of any changes seen in this subcategory.

Refining the conceptual framework. While this summation was being done for all teachers, the conceptual framework was formatted to show more clearly the contrasts between several different positions that were emerging from the interview data and from other research (Smith & Sendelback, 1982; Smith & Anderson, 1983; Hollon, 1987; Roth, 1989; Goodlad, 1984; Sizer, 1984). The newly-formatted framework presents the "goal positions" in a column titled "Scientific literacy focus," and two other sets of contrasting positions in columns titled "Discipline-based focus" and "Traditional focus." The "Scientific literacy focus" explicates the Goals and how they would be embodied in teaching; the descriptions that make it up are primarily theoretical perspectives taken from the research. The other two characterizations ("Discipline-based focus" and "Traditional focus") come both from conceptual contrasts to the literacy position (as described in the literature cited above), and the ways teachers described their orientations, goals, and approaches in the interviews.

The positions represented in each cell of the framework were revised several times, as subtle variations in the interview data revealed weaknesses in the framework. Each revision in the framework required minor adjustments in the associated codings in the interview data base.

Determining pre- and post-teaching positions. When all of the coding was complete and summaries of before- and after- positions were developed for each teacher, a position in one of the three focuses was determined for each teacher on each subcategory. Charts of teachers' positions were developed that summarized information from the analysis forms, by teacher and by subcategory. Table 3 shows a sample summary chart for two teachers on Goal

Table 3
Sample Summary Chart of Interview Positions

	LV	JP
1: l'ing goals	**before:** Learning to solve problems using scientific methods is most important, because it is a part of critical thinking. Content, on the other hand, comes relatively easily. DISC.-BASED (primarily Inquiry) **from teaching:** She spends time talking about the methods used to conduct this experiment, to help prepare students for the next time they do something similar. She has them use the results of their inquiry to discuss content. Also, she encourages them to ask their own questions, and cajoles them to be curious always. SCI. LIT. (uses inquiry to construct content) **after:** Understanding science content is important but difficult because of misconceptions. No mention of *using* content. DISC.-BASED (both content and inquiry) **change(s):** 1. From emphasizing process to emphasizing understanding of content. 2. From thinking that learning content is relatively easy, to thinking that understanding content is relatively difficult (because of misconceptions). [See 1: str's, where she argues that content needs to be reduced to help students understand some things better.]	**before:** content is what's presented in the book, with some vision of learning complex topics. DISC.-BASED **after:** understanding well enough to apply to everyday events; general skills are also important, such as comparing and contrasting. SCI. LIT. (Using knowledge) and TRAD. (Processes) **change(s):** Some vision of applying or using knowledge in everyday events.

1: Teachers' Learning Goals. (It also shows a summary of information on this subcategory from the *teaching* of one of the teachers, to be explained in the next section. The other teacher represented on this chart was not observed.) The positions represented in the chart, and the changes that can be seen in them, will be two of the sets of results of this study presented in Chapter 4.

Summary of interview data analysis. To summarize, the interview data was read and coded twice while the conceptual framework was developed. The first reading coded the interview comments with a large number of non-predetermined categories. This first analysis of the data was useful for developing the conceptual framework. The framework was then used for the second reading and coding of the data, where interview segments were coded with goal subcategories from the conceptual framework. Information about the teachers' positions and apparent changes was compiled by goal subcategories, and will be shown in Chapter 4.

Procedures for recording and analyzing classroom observations.

Classroom teaching was observed by the researcher and an assistant as five of the six[7] pilot teachers taught Lessons 6 though 8 of the unit. These lessons were chosen because the unit developers believed they contain the most essential and relatively complex content of the unit, representing a series of curricular and instructional elements linked to the conceptual framework.

Literal program analysis. To provide a structure for collecting data on the unit activities taught by each teacher, the "literal program" of each lesson was

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[7] One of the six teachers seemed uncomfortable with us observing in her classroom, and would not schedule any observation times prior to teaching the unit. She wrote two notes about how she utilized several student pages and overhead transparencies from the lessons, instead. These notes, unfortunately, provided much less detail than the observation notes taken in the other five classrooms.

determined and used to create a chart of elements of each lesson (Smith & Sendelbach, 1982; Smith & Anderson, 1983; the literal program for lessons six, seven, and eight is contained in the appendix). The elements represented in the literal program chart include the key questions posed by the teacher, the inquiries carried out by students, the discussions preceding and following activities, the writing activities of students, etc., all of the activities (broadly construed) that the teacher and/or students would be involved in if the teacher followed the lessons exactly as written. The literal program follows the steps of the "procedure" section in each lesson, using the same numbering system as is used for the "procedure."

Classroom observation data recording. A form was created that listed the literal program activities in one column, and provided writing space in two columns for "what the teacher does" and "what the students do." These forms were used during the classroom observations to keep a written log of what teachers said and did, and what students said and did, in cells that corresponded to elements of the literal program. The written log recorded as much of the dialog between teachers and students as possible, and notes about their activities.[8] This style of note-taking during classroom observations was used in previous studies of science teaching (Smith & Anderson, 1987; Blakeslee, Smith & Anderson, 1987) and is typical of many types of fieldwork research. The difference between this study's approach to classroom observation note-taking and traditional fieldwork recording is that the literal program was used as a framework into which the notes were compiled. This could be done because the teaching program had been specified ahead of time, by teachers agreeing to use the unit. If teachers deviated from the literal

[8] Speech and actions regarding the curriculum, not off-task social speech or behavioral disciplinary actions.

program, observations would be written in the element of the literal program that most closely corresponded to the teacher's activity.[9] Audio tape-recordings of the classrooms were not made, because of the difficulty of adequately recording student voices. Nevertheless, using the structure of the literal program, the observers were able to record data that allowed them to determine whether the teacher used each literal program element, and how, if at all, it had been modified. This was the primary goal of the classroom observations.

A completed set of classroom observations shows all the activities of teachers and students, including relatively verbatim transcripts of classroom discussions. These observation records allow the classroom activities to be compared directly to the elements of the literal program, in order to judge the extent to which teachers followed the unit or deviated from it.

Data compilation and analysis. Classroom observations were typed into a data base. Each record represented one element of the literal program. Separate fields were used to record 1) whether the teacher actually conducted this element of the literal program (or conducted it with modifications), and if so, 2) the teacher's activities, and 3) the students' activities. The three lessons are represented in 45 records for each teacher.[10] A sample record is shown in Figure 1.

To analyze the data, fields were also included in each record to code two goal subcategories (from the conceptual framework) to which this teaching segment might be related. Another field was used to write comments about

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[9] In one case, though, the teacher's deviation from the literal program was so severe that the structured observation table could not be used for keeping track of classroom activities, so notes were taken irrespective of the literal program and later fitted to it.

[10] Not all teachers taught all elements of the literal program, and not all elements taught by each teacher were observed.

what was happening in this teaching segment as it related to the marked goal subcategories. These fields can be seen in Figure 1. The researcher read each teaching segment carefully, comparing actions of the teacher and students to positions in the conceptual framework, and coded each segment when possible with one or two goal subcategories which applied to that teaching segment. He wrote comments that teased out the connection between what was seen in the teaching with the goal subcategory.[11] This method for analyzing the classroom observation data may be considered to be a "bottom-up" method, since it applied goal subcategories to the actual teaching, rather than making a priori assumptions about what goal subcategories might be seen in each literal program element.

The data base for each teacher was then sorted to compile comments under each goal subcategory. Those comments were searched for patterns, and a summary of classroom events under each goal subcategory was written. This summary was then placed with the summaries of "before" and "after" teaching positions developed from the interviews, as can be seen for "LV" in Table 3.

Counting classroom events. A second method was used to further analyze the classroom observations, one that resulted in "counts" of teachers activities as they relate to the goal subcategories. In contrast to the first method of reading the data and assigning categories, this method looks more like a "top-down" approach.

In developing the unit, activities were designed to embody aspects of the four goals; therefore it made sense to analyze the literal program for the goal

[11] Some teaching segments were not coded, either because they were not conducted by the teacher or because they did not provide substantial evidence bearing on one of the goal subcategories.

Figure 1
Sample Record from Classroom Observation Data Base

activity 3 3 Have students speculate about why ice is different from water (trans 5); draw out any ideas about molecules (brainstorming and questioning) (day 1, in order)	What makes ice hard, why does water flow? Why? Molecules? What's that? Can you see with naked eye? What are they? It's tough to understand things we can't see.	s1: Ice is solid, water liquid. s2: Because it's frozen tight. s3: Water's made of molecules. As molecules go slower they stop, but water is warmer, molecules just flow. They are like cells to things that are non-living. s4: They can be in living or non-living things.
name Duff **lesson #** 6 **done?** yes **goal?** 1 **sub** str's **goal2** **sub2** **comment**	So look at the ice cube and water. Can you see molecules? You won't see with the magnifying glass. You need a very, very powerful microscope.	(He let's several ss talk.) They're invisible. They're microscopic. 1st s explains bubbles in boiling water: they need space. Another s reads old paper on oil and water molecules.
He asks a good question here, to get students to think about underlying differences between ice and water. This unit seems to stimulate him or provide a good platform for asking good questions.	(He allows ss to tell what they already know.) What can we do with ice that we can't do with water. In the summer? Why can you swim through it? Let someone else, cuz I know you know. Why? (pause) It has to do with temp.	You can skate on it. You can swim through it 1st ss wants to answer. Molecules are tight. Mol's are packed closer together. Because it's frozen.

subcategories that each element embodies. Then each teacher's observations could be analyzed in a second way. Whether or not they actually conducted elements of the literal program that embody particular goal subcategories could be counted, as well as the number of times they conducted certain elements from one of the three positions.

To do this analysis, an intermediate data collection form was prepared that lists the entire literal program and includes notes about whether the teacher conducted an element (or conducted it with modification); the completed form is shown as Table 4, Summation of Literal Program Elements Taught, Coded by Subcategory.

Not all goal subcategories produced numerical counts. The specific ways in which the goal-subcategories were applied to the literal program and classroom observations are described below.

Goal 1: Teacher's learning goals (noted). A teaching sequence may show the teacher's commitment to one or more learning goals by the emphasis he or she places on big ideas vs. undifferentiated content, the extent to which students are asked to apply what they learn, and the way they use inquiry. This learning goal is *not* identified in column 2 (with one exception), because *most* elements of the literal program could contain information related to it. Any information about this subcategory is noted in the summary information in Table 4.

Goal 1: Approaches and strategies (a, b, c). *Instructional strategies* are noticed primarily in the ways teachers conduct inquiries and associated classroom discussions (or don't). Specific elements of the literal program that potentially provide information related to this subcategory are indicated in column 2 of the Table. Individual teaching sequences for each teacher are coded a, b, or c for this subcategory, as they describe the related goal position (a=scientific literacy focus, b=discipline-based focus, c=traditional focus). *Curricular approaches* are limited because teachers were required to use the unit as the curriculum. Extensive additions or changes were not made by any of the teachers.

Goal 1: Teacher's content knowledge (noted). The *extent* of one's content knowledge and pedagogical content knowledge is most often revealed in instances where teachers are responsible for presenting or jointly constructing knowledge with the class. Indications of the extent of a teacher's content knowledge are noted whenever they appear in a teaching sequence. (Their position on its *value* is more evident in the interviews, where there are also self-reports about the extent of one's content knowledge.)

Goal 1: Knowledge about students (gaining: yes or no; using: a, b or c). Teachers have opportunities to *gain* knowledge about students from discussions and students' written work, especially times when students make and explain predictions, brainstorm and state their reasons, or speculate about causes. Elements of the literal program that contain these student activities are so indicated in column 2, and the teaching sequence is coded as yes (the element is done), yes with modification (the element is partially done or modified), or no (not done). Teachers can be seen *using* this knowledge whenever they respond to students; this knowledge is a key element in strategic teaching, including scaffolding and coaching. Use of this knowledge is coded as a, b, or c (as above).

Goal 2: Important activities (yes or no). Elements of the literal program that call for, or that allow teachers to choose to have students, explain, predict, describe, design, construct new knowledge, or reflect on knowledge, are coded as yes (done), yes with modification, or no (not done).

Goal 2: Real-world contexts (yes or no). While the unit is primarily about the real-world contexts of water, ice, and snow, it can be taught as a theoretical presentation of the molecular structure of matter. Therefore several opportunities exist for focusing directly on real-world contexts rather than on theoretical explanations. Those literal program elements are so coded, and the teacher's observations are checked as yes, yes with modification, or no.

Goal 3: *All* students (a, b or c). Sequences that show teachers making various efforts to include all students or to specifically provide support for underrepresented groups are coded as a, b, or c, as explained above.

Goal 4: Across science disciplines (noted). This subcategory takes into account any instances of teachers making connections to other science subjects that their students have studied. Noted as they appear in observations.

Goal 4: Across other subject matter areas (yes or no). Tasks that call for extensive writing or reading, or any use of mathematics, art, dramatic expression, or that connect to social studies issues are so coded. Teaching sequences were then coded with yes (the teacher had students do these tasks), or no (they didn't).

This chart summarized the classroom observations in ways that allowed the teachers' teaching to be compared to the literal program, showing the extent to which they conducted the elements, and allowing the numbers of times they conducted activities related to the goal subcategories to be counted. The complete chart is in the appendix. The results of this analysis are presented in Chapter 4.

Table 4
Sample of Literal Program Elements Taught, Coded by Subcategory

literal program element	goal subcategory	LV	KB	FE	TF	SJ
Lesson 6						
Part A: Students discuss as a class how ice and water are different, and speculate about what accounts for these differences.						
1 Set up problem for the lesson: *why* is ice different from water. Students handle samples.	2:r-w contexts	Lesson 6 not observed, but some items from this lesson were used in lesson 7, as noted	yes w/ mod.: "Why is ice hard but water flows." (1st)	Lesson 6 not obs'd, but teacher reported that students were very engaged	yes w/ mod.: "Why is ice hard but you can put your finger through water?"	no; students handle samples in 2
2 Have students list descriptive differences between ice and water, on board or trans 4 (discussion)	2:r-w contexts	yes (repeated in L7)	no		yes	yes; story-line question-ing
3 Have students speculate about *why* ice is different from water (trans 5); draw out any ideas about molecules (brainstorming and questioning)	1:str's 1:k of ss 2:imp act's	yes (in L7)	yes (2nd); a		yes	yes; b
Part B: Teacher and students construct the molecular description of solids and liquids, using discussion, models, pictures, reading, and role-playing.						
4 Present the molecular explanation of solids and liquids (use picture on trans 6, clay model) (lecture)	1:t cont k 1:str's	made clay model	yes w/ mod., using sp9 instead; story-line; unrespon-sive to naive conception s (3rd); a		yes, did not use a model; b	yes w/ mod.: constructs with class, used two models, did not respond to naive ideas; b

Table 4 (cont'd)

literal program element	goal subcategory	LV	KB	FE	TF	SJ
5 Use bodies to make model; teacher points out salient differences (activity)	4:acr s-m	yes (in L7)	yes (5, beginning of day 2)		yes, w/ mod.: asks Ss to discuss	yes; b
6 Read sp 6a and 6b (reading)	4:acr s-m	yes, after freezing experiment of L7	yes (4)	no; passed out during L7 freezing activity, but ss never read it	yes, out loud, w/ ss taking turns	no; passed out but not used; explains freezing
Part C: Students use knowledge of molecules to 1) explain why you can skate on ice (not water) and swim in water (not ice), and 2) describe the inadequacies of "the brick analogy"						
7 Discuss as a group or work individually to answer questions on sp 7a and 7b, Ice on a Pond (5 questions; picture also on trans 7) (writing)	1:l'ing goal 1:str's 2:r-w contexts 2:imp act's 4:acr s-m		yes, pushing ss to think (6th); b		yes, in groups; missed naive statement; b	yes; did not address student's naive conceptions; b
8 Discuss what's wrong with stacked and heaped bricks as analogies to ice and water molecules, trans 8 (discussion)	1:str's 1:k of ss		no		yes; students responded, but no debate or discussion; c	no

Use of the classroom observation data in relation to the interview data

How do the classroom observation data relate to the interview data? Do the classroom observations show the effects of the unit on how the teachers teach, or do they show the effects of the teachers' (hard-to-change?) routines on the unit's literal program?

Should they be used to confirm what teachers say in the interviews, to make a point about whether teachers actually teach from the positions they espouse? Or should they be used to "triangulate" teachers' positions, adding independent information to what was gained through the interviews?

Given the commitment of this study to the findings of research on teachers' thinking, planning, and decision-making (e.g. Clark & Peterson, 1986) that teachers make many instructional decisions as they teach, using the information available to them from their environment, this resesarch takes the position that new materials present new information to teachers and therefore help shape their instruction, more so than the teachers' existing routines shape the pedagogy suggested by the unit. That being the case, the observation data does provide useful information that is some mix of the effects of the materials and the impact of teachers' past practices. It therefore is viewed as independent to the interview data, rather than as confirming the interview data. In those cases where teachers will show changes in their positions, the observations provide information about their practice in transition.

As an example of how the observation data was used with the interview data, consider the literal program element in Lesson 8 where students were asked to design their own experiment to test their prediction about whether the weight of an ice cube would change after it had melted into a puddle of liquid water. Several teachers did not let their students design the experiment. Ms. Fletcher was one who did not. Nor did she allow them to process the results of the investigation and draw conclusions, preferring to show them how to set it up and tell them what it meant. Her position on the Goal 1 subcategory of Teachers' learning goals, as indicated by this approach to Lesson 8, would be that learning how to construct knowledge, or learning content through conducting inquiries, was not important for her. In the interview, she pointed out what she considered to be problems with using experiments to establish content: That if it takes too long, or if it takes students off in the wrong direction, then it is not a valuable tool for learning content. In this case, considering the observation data to be independent of the interview data—that one did not determine the other—it can be seen that her practice sheds light on what she meant by her interview statements.

The classroom observation data, then, was considered as independent data, and a position was determined on each goal subcategory for each teacher, where observation data existed. As will be seen in Chapter 4, it was also used in describing changes that occurred in many of the teachers.

Summary

The procedures used in this research were derived from research traditions to which this study hopes to make a contribution, and adapted for the purposes of the study. Teachers were interviewed using a clinical interview format, and their positions on the reform goals were deduced by synthesizing their interview statements. A conceptual framework was developed, based on research and teachers' interview responses, to explicate the goals and provide contrasts to them that appear in actual teaching.

Participants' classrooms were observed, and notes written regarding the actions and speech of the students and teachers as it related to the literal program. Teachers were asked, in post-teaching interviews, to explain their reasons for the actions they took, especially when they deviated from the literal program, and what they liked or learned from the unit. Their responses revealed their positions on teaching and curriculum, which was taken as evidence of their positions on reform goals, as explicated by the conceptual framework.

CHAPTER 4: RESULTS OF THE STUDY

Several sets of findings are presented in this chapter. Two sets deal with the positions held by teachers on reform goals, and the changes seen in their positions as they used newly designed teaching materials. These findings are the empirical results of this study. Another set of findings concerns general patterns of positions on the goals, as they emerged across various teachers in the study. These are primarily conceptual results.

Two final sections of findings from this study concern the methodology used to conduct the study, and what has been learned about the conceptions of the reform goals themselves.

Patterns of Teaching Across the Reform Goals

Two patterns of positions on the goals—both of which contrast to the scientific literacy position—emerged from the interviews and classroom observations (and were fleshed out with insights from the literature). These patterns are constituted by relatively coherent, related positions on goal subcategories. They are presented in Table 5 below, juxtaposed to the scientific literacy positions presented in Chapter 2. The table is referred to as "The Conceptual Framework of Positions on Goals and Subcategories," or simply "The Conceptual Framework."

The two emergent patterns, as well as the scientific literacy goal positions, are described in the conceptual framework as a collection of narrative statements about each position. Each pattern is referred to as a focus, indicating that a teacher who fits in that pattern has that focus around which his or her beliefs, goals, and approaches to teaching and the curriculum revolve. Each pattern could be thought of as a constellation of positions on the goals that are internally consistent or that have some defining logic to them. That defining logic is captured by the title of the focus: Traditional, Discipline-based, or Scientific literacy. On the Conceptual Framework, each focus is represented by a column in the table.

Table 5
The Conceptual Framework of Positions on Goal Subcategories

	Scientific literacy focus	**Discipline-based focus**	**Traditional focus**
GOAL 1: UNDERSTANDING			
Teachers' learning goals[1]	**Using scientific knowledge**: To know content deeply, in its connections to other ideas and its application to the real world (that is, to understand how the world works, to be able to use knowledge to describe, explain, predict, and design specific phenomena, systems, and events). **Constructing and reflecting on scientific knowledge:** To be able to use inquiry skills and habits of mind to develop deep understanding of content. **Empowerment:** To be empowered to act in the world by one's knowledge, skills, and habits of mind.	**Big ideas**: To know the big ideas of science — but not necessarily to *use* the big ideas to understand how the world works. To know *how* we know the big ideas of science, the methods used in each discipline and the kind of evidence that has been produced for the discipline's theories. **Inquiry:** To be able to use the methods of science to solve problems and think critically, across all kinds of content. Inquiries are not conducted necessarily for learning content, but for learning how to inquire. **Excitement:** To be excited about science.	**Coverage:** To have an acquaintance with the content of science, as represented by its facts, definitions, and laws. **Processes are paramount:** To be able to find information when needed, use the processes of science generically (without regard for content), know the steps in the "scientific method", etc. — since "content is changing so rapidly." **Fun:** To have fun or develop positive attitudes towards science.

[1] The scientific literacy learning goal integrates the dimensions of activity, knowledge, and contexts, where the discipline-based learning goal keeps them separate.

Table 5 (cont'd)

	Scientific literacy focus	Discipline-based focus	Traditional focus
Use of curricular approaches and teaching strategies	**Strategic teaching:** Students must be given opportunities to work with materials, to pose questions, struggle with evidence and alternatives, and articulate their thinking. Amount of factual detail and number of topics must be reduced to allow time for this. Key questions, problems, and inquiries must be chosen well to allow opportunities for deep thinking that challenges students' naive conceptions. Teachers scaffold students' developing understanding; create a learning community in the classroom.	**Story-line:** Content should be presented in a coherent story-line, in a way that gets students to think and not just memorize. Content is determined by the discipline.[2] Hands-on activities illustrate concepts, while emphasizing science as a process, and adding interest to lecture and reading, but are mostly canonical and do not tap into students' conceptions. —or— **Discovery approach:** Hands-on activities are used to weave the story-line, more than lecture and discussion.	**Follow the book:** Cover the book, without emphasizing the big ideas of science; answer questions from the book or from worksheets; add activities when possible to show that science can be fun. —or— **Activity-driven:** Rely on activities to teach the curriculum, with little explicit attention to the ideas behind the activities. Use of sophisticated techniques (for working in groups, designing experiments, etc.) is not uncommon.
Teachers' content knowledge	**Pedagogical content knowledge** is valued as well as disciplinary content knowledge because they undergird strategic teaching.	**Disciplinary content knowledge** is important.	**Teacher generalist:** "If you can teach, you can teach anything. Just follow the book."
Knowledge about students	**Students' conceptions:** Knowledge of individual students' developing understanding, as well as potential barriers to understanding, is essential for teaching and planning, and must be gained on an on-going basis through interactions with students or their work.	**Developmental knowledge:** General knowledge of what is appropriate for students of certain ages is gained by years of teaching, and is useful for curriculum planning. **Aware of examples:** Occasionally students have misconceptions that need to be changed, but how their understanding develops is less important than their performance on tests.	**End-state knowledge:** The teacher's role is to present the subject, while the students can chose to learn it or not; therefore knowledge of their developing understanding is unimportant. Knowledge of their end-state is important for grading.

[2] There may be some conflicts in these teachers between covering all the content assigned by the discipline and constructing thought-provoking story-lines.

Table 5 (cont'd)

	Scientific literacy focus	Discipline-based focus	Traditional focus
GOAL 2: USEFULNESS AND RELEVANCE			
Important activities	**Outside-of-school:** Important activities are what students will be expected to do outside of school (diagnosing, explaining and describing phenomena, applying knowledge, predicting and testing predictions, designing and constructing, reflecting on the merits of arguments, questioning, communicating, making connections, making decisions based on limited information, etc.)	**Scientists' activities:** Students must be able to explain the content, not just listen to it, using mathematics when appropriate; conducting experiments using appropriate methodology; note-taking, library research, and report-writing are important activities for future use.	**School-related:** Important activities are those that are needed to do traditional classroom-related tasks (note-taking, outlining text, answering questions about text, answering multiple choice questions on tests, etc.)
Real-world contexts	**Comprehensive:** All aspects of curriculum and instruction are embedded in real-world phenomena, systems, and events, as problems, applications, and connections. Learning requires drawing on students' everyday experiences with these contexts (as well as their theories about them). Also, science can be used to help understand and make decisions about social and personal issues.	**Canonical:** Hands-on activities generally use canonical or esoteric contexts. Field-trips show students how school learning connects to the real-world.	**Non-contextual:** Real-world contexts do not generally appear in the textbook, where the focus is more on vocabulary and theory.
GOAL 3: *ALL* STUDENTS			
Teacher's position	***All* students:** All students can become scientifically literate with appropriate encouragement, opportunities, and instruction; students should learn to accept diversity and appreciate the value of diverse ways of doing things.	**Restricted access to secondary science:** All students can get something out of science, and should take it in elementary school, but only those with sufficient interest and talent will understand the big ideas.	**Special gifts:** Some students can succeed in science, but others just don't have what it takes.

Table 5 (cont'd)

	Scientific literacy focus	Discipline-based focus	Traditional focus
GOAL 4: INTERDISCIPLINARY			
Across science disciplines	**Multi-disciplinary:** Many good problems can be solved only by bringing together ideas from several disciplines; the big ideas of science cut across disciplines.	**Prerequisites:** Some topics are prerequisite for others (ideas must build on foundations). **Connections** should be made among disciplines that show how theory applies in different contexts.	**Independent:** The disciplines, as represented in textbooks, are relatively independent.
Across other subject matter areas	**Integrated:** Expressive skills, knowledge from other subject matter areas (including mathematics and social studies), and knowledge gained from reading are used to support science learning.	**Partial:** Mathematics and report-writing are essential skills for doing science, and should be incorporated when possible.	**Superficial:** Unrelated learning goals from several subjects may be accomplished at the same time by addressing them under a loose thematic umbrella.

Reading the table across the rows, one sees three contrasting positions that attempt to describe the range of positions on each goal subcategory taken by teachers in the study. Each cell contains one or several formalized statements about a position which are intended to help "map the landscape" of possible positions on the goal subcategories. When a cell contains more than one formalized position statement, it is often because there are several components of that position (see "Goal 1: Teachers' learning goals" as an example). In two cases ("Goal 1: Use of ... strategies," the "Discipline-based focus" and "Traditional focus") two alternatives are presented in each cell.

The Discipline-based focus. The first set of contrasting goal positions is named for their general alignment with the disciplines of science (not for the ways in which teachers deal with students who speak out of turn). It is a set of positions whose common thread is to prepare students to be scientists, to understand well the theories of the discipline, to appreciate how knowledge is gained, and to be mentally prepared to do scientific work.

This middle position is an attempt to document the difficult and demanding teaching approach of those who understand the science disciplines well and want their students to understand them as well, see the value in pursuing them, and be excited about science as an approach to knowing about the world. The "didactic/story-line" and the "discovery" teachers written about by Smith & Anderson (1983) fit in this category (under the subcategory of Goal 1: Strategies), as do the "content understanding" teachers in Hollon (1987; see also Roth, 1989). Teachers in the discipline-based focus would say (as one teacher in the study did) "When they have a very good understanding of it, when they will always remember it, [is] when they learn it so well that they can explain it to you."

A unique aspect of the conceptual framework is its description of this middle position. Most contrasts used in the reform literature are to elements of the traditional position (e.g. Promoting understanding over *content coverage*). Those contrasts make the choice between positions rather easy for most teachers. But for many teachers, teaching from the discipline-based focus is important, responsible, and appropriately challenging.

One major difference between the scientific literacy focus and the discipline-based focus is the idea of *using* scientific knowledge in real-world contexts, for social and personal purposes (as described in Goal 1: Teachers' Learning Goals). Until the notion of using scientific knowledge was described in the reform literature (cf. Rutherford & Ahlgren, 1990), it was not evident what was missing from the "discipline-based" position. This position had served many students well, especially those with an interest in science, a desire to enter a scientific career, and a strong aptitude for school work. And it incorporated real-world contexts, at least canonical ones.

It was mostly through the efforts of the research community, who showed that even the best discipline-based teaching leaves many students without the clear understanding of scientific ideas that it expects (Anderson & Smith, 1987), and furthermore leaves many students feeling that the world of science has no connection whatsoever to their everyday world (Roth, 1989), that this contrast began to take hold.

Goal 2 also represents this contrast. "Important activities" for the discipline-based perspective include explaining the content, conducting experiments, doing library research, and writing reports. These activities are really more of a parody—or, more kindly, a "classroom version"—of what scientists do than the actual activities of scientists, yet these are the kinds of activities most often described by discipline-based teachers (as well as by many teachers who otherwise fit in the scientific literacy focus).

The other striking contrast between the discipline-based focus and the scientific literacy focus concerns Goal 3, the issue of who should be involved in science and who should succeed. The discipline-based focus is concerned with those who will be inducted into the discipline. This was satisfactory as long as it was necessary for only a small percentage of students to succeed in science.

A major difference between the three focuses can be seen in the kinds of knowledge that teachers need to teach within each focus (Anderson & Smith, 1987). In the discipline-based focus, teachers only need deep knowledge about the content; some teachers also possess developmental knowledge—gained from their experience—about students' general abilities. But in the scientific literacy focus, teachers also need knowledge about students' developing understanding and typical naive conceptions in the topic, as well as topic-specific pedagogical strategies. Without this additional knowledge, effective strategic teaching cannot occur.

The Traditional focus. The Traditional focus describes an approach to the curriculum and teaching that has characterized much of science education (and education in the other disciplines) for decades (Smith & Sendelback, 1982; Smith & Anderson, 1983; Hollon, 1987; Roth, 1989; Goodlad, 1984; Sizer, 1984). In this approach, students are considered to be passive recipients of knowledge, teachers do most of the talking, students' activities are confined primarily to reading texts (without any significant guidance for making sense of it), and the content is not differentiated between facts, concepts, and overarching theories. The term "delivery method" is used to describe the choices a teacher has in traditional teaching, because the conception of teaching is that the content is delivered to students, and they assimilate it. The characteristic cognitive activity engaged in by students in this focus is memorization of facts.

This is the style of teaching and the approach to curriculum that has turned off so many students from science. Because of this, some teachers in this focus have adapted their goals and their techniques to try to make science exciting and to use strategies that engage students in hands-on activities. Even so, this updated version of the traditional approach falls short of the scientific literacy approach in its failure to emphasize important content and activities, and its failure to appropriately scaffold student learning. Smith & Sendelback (1982) described the "activity-driven" position of many teachers involved with "hands-on" science: They believed that their students would learn what was necessary about the content by conducting the activities of the science program, without any discussion to focus or resolve the issues that the activities were intended to inquire into, and without any attention to naive conceptions of the topic that students have. This position is described under the traditional focus in Goal 1: Strategies. Hollon (1987) described the "fact-acquisition" perspective on teaching, from which the Goal 1: Teachers' learning goals position is partially derived.

The position in the traditional focus on who will succeed in science is one that was based on the observation that, given this style of teaching and this approach to the curriculum, only a few students were able to do well and advance. The logical conclusion was that the ones who did not advance were not capable of it. This is in contrast to the scientific literacy position that, with appropriate support and encouragement, all can succeed, and all *need* to succeed.

While it was possible to create a parody of good science teaching in the "traditional" focus, every effort was made to write about the positions in ways that described responsible teachers making rational decisions about teaching. Still, the claim here is that neither the traditional focus nor the discipline-based focus are adequate to prepare students for the scientific and technical demands of the workplace or citizenship, either because they do not effectively help most students learn well the big ideas of science, or because they fail to connect those ideas with the phenomena, events, and systems of the real-world.

Teachers' Specific Positions on the Goal Subcategories

Through their interviews and their practice, teachers' in this study displayed varied positions on the reform goals. Those positions are shown in Table 7, Teachers' Positions, below. The specific ways in which they were derived from the interviews and classroom observations are briefly discussed in the two sections that follow; the table displaying teachers' positions is then introduced; and a narrative description of each teachers' positions concludes this section.

Results from the interviews. As discussed in Chapter 3, teachers' positions on the goal subcategories, as deduced from the pre-teaching and post-teaching interviews, were summarized in charts; an example was shown in Table 3. The summaries were compared to the conceptual framework, and each teacher was placed in a position for each goal subcategory. Those positions are displayed in Table 7, below.

Results from classroom observations. Teachers' positions on the goal subcategories, as indicated in the classroom observations, were determined in two ways, from a "bottom-up" coding of the interview data base, which resulted in notes and positions being added to the interview data summary charts, and from a "top-down" analysis of the teaching by literal program element, summarized in Table 4. That intermediate data summary chart was then used to count and otherwise make note of the extent to which teachers conducted various elements of the literal program that embody certain goal subcategories. The results of that "top-down" analysis are shown in Table 6, below.

Three types of notes are used in Table 6. Numbers are a count of how many times teachers used a teaching element related to a goal subcategory, out of how many total teaching elements were available to them that related to that goal subcategory—where teaching that element at all normally has the results desired by the unit. These elements are counted as having been taught if either they were taught as written or taught with modification. These numbers vary across one goal subcategory because teachers were observed teaching different amounts of Lessons 6 through 8.

Table 6
Summary of Teaching by Goal Subcategory

goal: subcategory	LV	KB	FE	TF	SJ
1: learning goals	a: "Ask questions always!" a: using inquiry to construct content	not a: He would not use an activity to construct content	c: strong process orientation in L7		
1: strategies (regarding use of inquiries and content presentation: L6 discussion, L7 experiment, L8 experiment)	L6: na L7: 3 a's L8: na	L6: 1 a, 2 b's; story-line, "Think hard!" L7: 1 a, 1 not-a L8: 2 a's, 2 b's	L6: na L7: c L8: c; activity driven	L6: 2 b's; 1 c; activity driv. L7: 1 a, 4 b's, 1 c L8: 1 a, 2 b's, 2 c; story-line	L6: 4 b's; story-line L7: 1 b L8: na
1: teacher content knowledge	a: learned by teaching the unit the most subtle idea: force between mol's	not a: weak content specific pedagogy: did not distinguish freezing/ melting from solid/liquid	not a: weak content specific pedagogy: no discussion follow-up to freezing experiment		b: learned from unit that the critical difference between solids and liquids is not distance btwn mol's
1: gaining knowledge of Ss 1: using knowledge of Ss (instances)	3 of 5 a: listened to students' comments and responded appro-priately	4 of 11 not a: did not respond to naive ideas twice	1 of 7 can't tell if unresponsive bec. not much discussion	10 of 11 b; brought up and corrected one naive idea; not a: did not respond to naive ideas 1x	1 of 7 not a: did not respond to naive ideas twice
2: important act's	6 of 8	6 of 13	6 of 9; she followed the unit closely, but missed 4 opportunities for significant discussion following activities	9 of 13; did not let Ss design the exp. in L8; did not discuss 3 times	2 of 9
2: r-w contexts	2 of 4	4 of 9	2 of 5	7 of 9	3 of 7

Table 6 (cont'd)

goal: subcategory	LV	KB	FE	TF	SJ
3 (all students)		1 a: deliberately involved all students in 1 activity	a: used groups extensively for purpose of involving all	a: deliberately involved all students in 1 activity	
4: across science disciplines	discussion of "cells" tied to earlier unit: a				Student asked about cells, but teacher did not respond: not a; story-line
4: other subject matter areas	2 of 4 plus other writing	3 of 6	1 of 3; no extensive reading or writing act's used	5 of 7; did not allow Ss to graph data in L7	2 of 6

Letters "a," "b," and "c" are used to code teaching sequences that most closely fit one of the positions on the conceptual framework (a=scientific literacy focus, b=discipline-based focus, c=traditional focus; na=not applicable), where simply counting if that literal program element was taught does not record the essential nature of *how* it was taught. Short text is used to make a note of some aspect of their teaching in that category.

The results from this second analysis of classroom events was synthesized with the information from the first analysis (which is shown on the summary charts for the interview analyses) to produce the "teaching" position ("t'ing") for the teacher, as shown in Table 7, below.

Table of teachers' positions on the goal subcategories. In Table 7, teachers' positions are summarized for each goal subcategory in terms of the Framework's three general conceptions of science education: the Scientific Literacy Focus, the Discipline-Based Focus, and the Traditional Focus. Details of individual's positions on certain goal subcategories will be highlighted in the section that follows, where individual cases are discussed.

Changes in teachers' positions can be viewed in a general way from the table below. Several interesting and positive changes were found; the cells that contain those changes are shaded. Changes ranged from being about the broad strokes of the curriculum to being about the specific details of teaching and learning. The specific changes are detailed in the stories, below.

There are several ways of looking at the results represented in this table. The first is by goal subcategory. Reading across the table gives an overview of where teachers stood on each goal's subcategories prior to using the unit (pre), from their teaching (t'ing), and after using the unit (post). The first row, for example, shows that all teachers in the sample held *discipline-based* positions on learning goals prior to using the unit, and those positions were rarely affected by the use of the unit (that is, most teachers held the same position on learning goals in the post interview).

The second is by teacher. Reading down the table, each teacher's positions are shown. One can see, for example, that Ms. VandenBerg's teaching is quite consistently of a "scientific literacy" style. Mr. Bowden can be seen, prior to using the unit, as "discipline-based" on Goal 1, but in the "scientific literacy" position on Goals 2, 3 and 4. Mr. Jordon's teaching is consistently from the "discipline-based" position (where information is available).

Changes in teachers' positions can usually be seen from examining each cell; the shading draws one's attention to subcategories and teachers where changes are evident from the interviews and classroom observations. In all but one of the shaded cells, the change can be read from the codes in the cell. The exception will be explained in detail below (the exception is for Ms. Fletcher, on Goal 2: Real-world contexts).

Table 7
Teachers' Positions on Goal Subcategories

	LV pre t'ing post	KB pre t'ing post	TF pre t'ing post	SJ pre t'ing post	FE pre t'ing post	JP* pre t'ing post
1: l'ing goals	▲ ■ ▲	▲ ▲ ▲■	▲ _ ▲	▲ _ ▲	▲ ❑ ▲	▲ _ ■❑
1: strate-gies	▲ ■ ■	▲ ▲ ▲	▲ ▲ ▲	▲ ▲ ■	_ ❑ ❑	▲ _ ■
1: content knowl	■ ■ ■	▲ _ ■	▲ _ _	_ ▲ ▲	▲ _ _	■ _ ■
1: knl abt ss	▲ ■ ■	▲ ▲ ▲	_ ▲ ▲■	_ _ ▲■	▲ ▲ ▲■	▲ _ ▲■
2: imp act's	_ ■ ▲	■ _ ❑	■ ■ ■	_ ▲ _	_ ▲ ▲	_ _ ▲
2: r-w cntxts	▲ ▲ ▲	■ ❑ _	_ ■ ■	_ ▲ ■	_ _ _	_ _ ■
3: all ss	_ ■ ■	▲■ ■ ■	_ ■ _	▲ _ ▲	▲ ■ ■	❑ _ ■
4: acr sci disc	_ ■ _	■ _ ■	_ _ _	_ _ _	_ _ ▲	_ _ _
4: other s-m	■ ■ ■	■ _ _	▲ ▲ _	_ ▲ ▲	■ ▲ ■	_ _ _

key:	❑ traditional	▲ discipline-based	■ scientific literacy	_ no information available	▲■ or ■❑ a mix of the two positions	shaded cells indicate sub-categories where changes occurred
	pre: from the pre-teaching interview	**t'ing**: from classroom observations	**post**: from the post-teaching interview		* JP was not observed.	

There are 162 positions that can be held by the six teachers in the study, three each (pre, t'ing, and post) for the nine goal subcategories. Of those, no information was available (or not enough information was available to make a categorization) in 57 instances. Eight of those instances were due to the fact that the researcher could not observe Ms. Preston's teaching.

Teachers' positions on the goal subcategories were almost always in the "discipline-based focus" (53 instances) or the "scientific literacy focus" (41 instances). Only seven positions were classified as "traditional focus.[3]" Five positions were "mixed"—that is, in those instances the teachers' positions reflected features from both categories.

Broad descriptions of each teacher. By the end of the use of the unit, two teachers (Ms. VandenBerg and Ms. Preston) could be seen as strongly in the scientific literacy focus; Ms. VandenBerg through her approaches to teaching as recorded in the classroom observations and her voiced commitments in the post-teaching interview, and Ms. Preston, through her comments in the post- interview.

Ms. VandenBerg's classroom instruction and activities gave strong indications of teaching for scientific literacy. She used the inquiries in the unit as a basis for discussing ideas. She urged her students to employ the habits of mind of scientifically literate people ("Ask questions always!") She taught strategically, discussing with students their thinking, especially when it seemed naive. Students listened to each other during discussions, clapped for each other, debated ideas, even asked her to ask them more questions; there seemed to be a "learning community" in her classroom. In her post-

[3] This may be a selection effect: The teachers were selected generally by recommendation, and even though the researcher asked the recommenders for teachers who spanned the range of teaching experience and ability, mostly competent and/or thoughtful and/or motivated teachers wound up in the sample.

interview, she talked often about students' naive conceptions and how difficult they are to change.

Ms. VandenBerg's post- interview comments do not put her completely in the scientific literacy focus, especially in the "learning goals" subcategory of Goal 1 and the Goal 2 subcategories: She did not articulate the idea of using the scientific knowledge that her students were learning, in real-world contexts. But her teaching indicated that other aspects of the "learning goals" subcategory were important to her (using inquiry to learn content; using the habits of mind of scientists), and she consistently used the activities in the unit that had students doing "important activities" in real-world contexts.

Ms. Preston's post- interview comments placed her squarely in the scientific literacy focus. She believed that the purpose of science learning was to be able to apply what you learned when you walk outside, that the amount of content should be reduced to allow more time for in-depth exploration, and that students' naive conceptions need to be taken into account when teaching them.

A third teacher, Mr. Bowden, had a split of positions. On several Goal 1 subcategories he showed positions that were partially in the scientific literacy focus and partially in the discipline-based focus. He believed that the content and methods of science are important because of what they enable student to do or appreciate: Content helps students make decisions about important social issues (he taught about primarily environmental issues) and method helps students solve problems (he had his class spend three weeks each year on science fair projects where the actual problem they investigated was not as important as the learning to follow "the scientific method"[4]). He also

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[4] "Like I told the kids today after their presentation, I said I hope you learned a lot about what you did, but more important than that, I hope you learned how to use the scientific

believed that "to see the details in the world around us makes life more interesting." (Post- interview, record 156.) But he did not articulate a conception of using scientific knowledge in mundane situations (just in environmental issues), nor did he recognize (even in his observed teaching) the power of using inquiry to learn the content. Content and method were basically independent aspects of science for him. Content was defined by the district curriculum, except in a few cases where he had developed his own units and projects. He did not articulate a notion of reducing content coverage to teach for understanding.

He was, however, a wonderfully engaging story-line teacher. He wanted his students to think deeply, and not accept knowledge on authority. He used strategies in his teaching that showed his commitment to involving *all* students. This was most obviously when he spent a great deal of class time asking *every* student in the class to make a prediction for the experiment of Lesson 8 and explain their prediction, as he wrote on the board and helped them clarify their thinking. He used this occasion exactly as it was intended, as a brainstorming session where everyone could begin to think about the processes going on in the experiment, and where no one's ideas would be denigrated before the actual experiment was conducted. He did not reflect negatively on anyone's comments. This was part of his excellent control over his teaching methods.

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method outline. And then I had them write down the steps for the scientific method outline that I use, you know they vary, but the one that I use, and all of them could do that, so they really have a general idea of what things are. And I told them they're going to use these for the rest of their school lives, and if they pursue science careers, they'll use them forever, so I think it was a very valuable lesson." (Pre- interview, record 37.)

As will be seen in the stories that follow, what he learned through using this unit, combined with his pre-teaching positions on Goals 2 through 4, probably provide him with a strong base for developing the scientific literacy positions on Goal 1 at some time in the future.

Two of the teachers—Mr. Jordon and Ms. Fletcher—were very oriented toward the discipline (notice the predominance of triangles in their columns). They were teachers who wanted their students to think hard about the big ideas of science and not just memorize facts. They taught by articulating—between themselves and their students—coherent story-lines about the content[5]. They were thoughtful of what they did to present material (using activities, overhead transparencies, concept maps). Conducting investigations was problematic for both of them[6] even though they took the position that hands-on activities were crucial for good science teaching. They did not have strong feelings about being interdisciplinary (except for using mathematics when appropriate).

They each mentioned some connection between science and the world, but neither elaborated on their comments: Mr. Jordon spoke of science as "an everyday event" and Ms. Fletcher believed that students should know content well enough to transfer it to new situations. These comments were undoubtedly important to each of them, but did not seem to be the central

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[5] TF taught the unit following the literal program more precisely than any of the other teachers.

[6] SJ stated that he used activities whenever he could: "The more activities that I feel I can use with the students, again, that's my way of hopefully helping them to have fun and realize that science is an everyday occurrence, trying, to a certain extent to give them that "Wow" impression but also realizing that, that isn't always possible." (Pre- interview, record 31) But the way he conducted the observed investigations was quite different from the intended literal program. He did most of the activity, without real participation on the part of the students. TF, on the other hand, said in her pre- interview that even though hands-on activities are critical to learning content well, she has had a hard time finding good activities that complement what she teaches, and that getting equipment is difficult.

driving force of their curriculum or teaching. As will be seen below, what most interested the two of them from the unit was its use of real-world contexts.

The sixth teacher, Ms. Estrada, said repeatedly that experiments are necessary to learn, and that they must be meaningful. She focused in her teaching primarily on conducting inquiries, working in groups, learning the methods and skills needed. She had very sophisticated methods for conducting activities: Her students had become very proficient at working in groups, and the designing of experiments was very important to her. She knew that students had prior knowledge and experiences that were sometimes naive, but she only used 1 out of 7 activities designed to help her gather information about students' developing understanding. She rarely lead sustained discussions among the entire class, preferring to have students discuss in groups, even though the literal program called for whole class discussions (she missed four opportunities out of 6 to conduct discussions called for in the literal program, where the two she did conduct were about the *results* of the experiments, rather than what the results *meant*). She seems to recognize this, in the interview comments that follow:

> Ms. Estrada: No, the kids didn't really ask about that [what holds molecules together as a solid], they really, because they, in their minds, they knew that solids were closer and wiggled a little bit as opposed to liquid. They didn't really question that, and *I don't know if I even [brought that out] even further so I'm not really sure if they got what they needed with that.* (italics added)
>
> Interviewer: Well, what we were striving for was that students had in their mind this mental picture, like these, that indicates that there is a

pattern in a solid, there's no pattern and the molecules are moving in a liquid.

Ms. Estrada: Through the drawing it shows that?

Interviewer: The drawing and the caption, because it's so hard to show that the molecules are moving or sliding past each other.

Ms. Estrada: OK, uh-huh, we didn't dwell on it but now I'm curious ....because *we did mention that* they were in a pattern and a few students did discuss that, *but we didn't really develop it any more than that, so I'm not sure,* other than the fact that when we acted it out, we did create a pattern, so *I think they might have, but I can't be 100% sure if all of them really saw that.* (post- interview, record 84)

She could most readily be categorized as an "activity-driven" teacher (under the Traditional focus, Goal 1, Use of curricular approaches and teaching strategies), where all of her teaching energy goes into preparing activities and teaching students how to conduct them effectively, with the assumption that they will learn what they need to learn as they conduct the activity and discuss it among themselves. There was no evidence in her observed teaching of her providing any scaffolding of learning.[7]

Out of the six teachers, then, two stated positions and/or demonstrated teaching that would put them in the scientific literacy focus. Three others fit mostly in the discipline-based focus (with one of those leaning toward the scientific literacy focus). And one (Ms. Estrada) mostly defied categorization, with her teaching looking like a 1990's version of a traditional approach, but

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[7] In all fairness, though, only two of her lessons were observed. Nevertheless, she had opportunities for discussing with students what they were learning from the investigations in those lessons, and did not do so in any sustained way that would help them make sense of the activity.

other positions ranging across the three focuses. All of them wanted their students to learn, to think, and to enjoy science.

Changes in Positions on Goal Subcategories: What Teachers Learned From Using the Unit

The above descriptions of teachers' positions did not highlight any of the changes that occurred from teachers using the unit. They were not unaffected by it. Each could point to something they liked or something they learned, some new way of thinking about the curriculum or some new teaching strategy. While none indicated that their teaching or conceptions of science education were transformed by using the unit[8], each was more glad than regretful that they participated in this pilot testing, for the fact that they saw something new or had their thinking jostled.[9]

The sections that follow describes those changes.

"Who's kidding whom?": Struggling with reducing content coverage to teach for understanding. One of the most noticeable changes in Joan Preston's positions on teaching dealt with the amount of subject matter that students should confront in one year (this is a change in her position on Goal 1: Strategies). She understood before pilot testing this unit that one of the new slogans in the science education community was "Less is More," but she

[8] But one teacher did rave about how well the unit "made a very difficult subject, very simple for kids to understand, for the teacher to understand": "I think it was magical, what you were seeing....I only saw a few times all year with this particular group. I see it all the time with my group but I wanted to do it with a more challenging group for you, cause you're not always going to get groups like mine and so....my group probably isn't even the norm, my own home room class so I wanted to do it with more of a normal class like you saw and the way they responded and reacted I only saw a couple of times all year so I think the unit's a very big success." (record 54)

[9] Actually, 5 out of 6 were complementary about their experiences with the unit. It seemed to the researchers that one teacher (LV) felt that this unit may have been about as good as her normal teaching. The change most readily attributable to her was more subtle than with others.

was not really sure that she accepted that approach. She believed that her students needed, liked and mostly understood all the content that her curriculum contained, even though she knew that she could not work her way through the entire textbook in a single year, doing it the way she wanted to. She had developed her own unit on topics similar to those in *Hard As Ice*, and it contained considerably more than the topics of molecules, solids and liquid, and melting and freezing. It also included content dealing with atoms, the nucleus, the periodic table, and chemical changes.

The question she had in the pre-teaching interview was: If my district curriculum tells me I'm supposed to teach about all these things, but you're saying I should teach less, how does that fit? I know I can't cover the whole textbook, that if we spend one week on the topic of ecosystems we're just skimming the top, but I do have this district curriculum to cover. Many district educators feel that we have this curriculum, we're responsible for it.

Ms. Preston: I guess I had just...I had done more with the atoms and you're saying in here that it really isn't necessary at this point?

Interviewer: Well that's what the state objectives say.

Ms. Preston: Yea, and I think that's OK, and still the kids... to be introduced to [atoms]... they were ready for it, it seems, and then when you get to the part with the molecules then I think it does become a little bit confusing, Wait a minute, this is an atom, what the heck is a molecule? And so we are... this would be a heck of a lot easier, I guess, for me, to... and they would understand this [better]... than to do all the other things I have done, although they have thoroughly enjoyed doing that and then they get into talking about the nuclear stuff and they have enjoyed that type of thing, so I don't know.

...

Ms. Preston: The other thing that bothers me is they're supposed to, as far as I know, they're thinking of starting a new science committee here next year and adopting a new science program, and that frightens me with this kind of thing [not teaching as much content each year], and then, I have to say that what we are doing is too much. I can't, I mean, what am I on, chapter 5 in the book, I mean, not that I'm reading the book only, there's 14 chapters in the book and I've got 6 weeks left. I don't think so...now again... something is....maybe this is the way to go and also a unit on the plants, you know, life sciences because there's so much in there that I really get bogged down. I'm going on the life science from September until January, because I feel all this stuff is in here, and as I said now we can forget chapters 6-14.

Interviewer: Well, a lot of people are recommending that, spend more time on one or two topics.

Ms. Preston: Right but then the entire curriculum all the way through has got to be changed. I think that's one of the main issues, there's too much, we're just skimming the top and there's nothing real firm there to take on, and then I stop and I think, my god, I haven't done electricity, I haven't done the solar system, I haven't done anything on weather and all that's important.

Interviewer: What is it exactly that bothers you about not getting to those other topics?

Ms. Preston: Thinking, well, they are in the objectives, so I'm not going to get there, next year am I going to have the sixth grade teachers say, god, doesn't she teach anything down there, you know what I'm saying?

...

Ms. Preston: I think we're all seeing that it's too much, that ... we have to skip some of these units at this grade level. And that's what we're doing in math now. I'm on a math committee and the language arts committee is going the same way: There's some things that they have to [determine are] important... but that's what's frustrating, when you think... these are the objectives, and Oh my god, I've got to cover these on the report card, what do I put?

Interviewer: You have a curriculum in the district, don't you, with topics and chapters.

Ms. Preston: Oh yea, but if I do that, I'm skimming the top, so what's better, see, I.. I.. that's a major decision and very frustrating.

Interviewer: Sounds like you're thinking everybody who's teaching science should agree on the curriculum?

Ms. Preston: Figure out what needs to be more in depth, and skip some of this other stuff. Now for instance, if this was just molecules [and not atoms], I don't know what else you would cover in that whole unit, do you get into your chemical and physical changes?

Interviewer: Physical changes in this unit, but chemical changes don't come in until the high school objectives.

Ms. Preston: But so if you had a unit like this that would cover these objectives, then it would be O.K., and I think we could do a better job then.

Interviewer: Just... I'm pretty sure I know what you mean, but when you talk about skimming the top because you feel there's so much to cover, what is it that you feel is the down side of that, that's bad about that?

Ms. Preston: I don't feel there's anything bad about it [reducing the year's content coverage to teach for longer time on one topic]. What's bad about it is I can't get to these other chapters, I can't get to this other stuff I'm supposed to cover, these other objectives I'm supposed to be meeting.

Interviewer: But if you do try to meet all of the objectives, then you wind up skimming the top?

Ms. Preston: Yea, then I end up skimming the top. What am I going to do? Read the book period? Now, who's going to do that?

Interviewer: You'd be surprised how many teachers do that.

Ms. Preston: I know they do, or none at all, I know that. It may be the majority at this point, but you take photosynthesis, that's a heck of a ....I don't know if it belongs in the fifth grade, but maybe just to introduce it.

Interviewer: It does, it does.

Ms. Preston: That's a very difficult concept. Was there another one too? On animals too, there's another long unit, in there, your vertebrates and invertebrates and then that ecosystem: I can't teach that in a week, who's kidding whom? (Pre- interview, records 93-97)

She voices in these pre-teaching comments her dilemma of, on one hand, knowing that complex topics can't be taught in the amount of time assigned to them if she was going to either follow the book or the district's curriculum, and on the other hand, feeling a responsibility at least to the other professionals in the district (if not to the students, as well) to teach all those topics and concepts. She does not articulate, in these pre-teaching comments, a rationale based on student learning for reducing content coverage, except to imply that to "skim the top" of a "very difficult concept" like photosynthesis might not be good pedagogy. At the very least, we can read in her comments that to try to teach, for example, ecosystems in a week would deny its essential complexity: "Who's kidding whom?"

Her preferred approach to managing this dilemma would be to have the district science committee "figure out what needs to be more in depth, and skip this other stuff." That is, have the professionals in the district come to some agreement that teachers should not be held responsible for addressing all the topics in the book, so they can avoid addressing them superficially. She is essentially saying that she feels responsible to the discipline, or the district, to teach what they assign to her grade, but, realistically, doubts that anyone can do that without skimming the top. As she entered her teaching experience with the unit, she had not made up her mind about which camp to live in. This is especially perplexing to her because she strongly believes that her students *enjoy* all of the topics she includes in her own unit.

At the beginning of her post-teaching interview she expressed the dilemma again, as if to put it on the table for herself to consider: "I'm having a little bit of a hard time because I guess the amount of material that I had covered—I'm thinking all the stuff these guys should be really knowing—instead of looking at it as at this point with fifth graders maybe this is all they can comprehend at this time" (record 119). But as the interview went on, she seemed to work out her position. She became convinced that slowing down the pace of instruction and not trying to cover the entire book was important, and not for the discipline-based reason that each topic necessitates a longer treatment, but because it is important for students' learning.

What she advocated was spending enough time on a topic so that students can stop and thoroughly watch the phenomena, as they stopped and spent time observing ice freeze in the unit ("I really like the idea that being so... and I never thought of this stuff myself... you know how the ice forms and the stages that it goes through, I liked that real well, and I don't think anyone is real conscious of that thing and I really liked that part of it" post- interview, record 115, actually the first statement she made in the post- interview). Spending enough time on a topic so that students can examine its phenomena is crucial to students' learning, she argued, because they can then *use* what they learn outside of the classroom. They can know enough, for example, not to be the "dummy driving out on the lake and going through." (post-teaching interview, record 125)

Ms. Preston: I like the unit, I like its detail, like I said I was impressed with that part of it really [where they] stop and watch it [the ice freezing], and I think it's great that we do that kind of thing. (post-teaching interview, record 122)

...

Interviewer: We're hoping that in some ways these units can help encourage teachers to try new approaches for teaching. Do you think that's going to be true at all? Can you see any ways that might happen?

Ms. Preston: I would hope that this is the way to go, I really like the idea of one thing... (pause)

Interviewer: Just focusing on one thing?

Ms. Preston: Staying and just really getting into that, instead of all of this stuff. I don't think they really learn anything and remember it [when all of this stuff is taught]. To me by doing this, the kids are going to remember seeing that ice form when they're going outside or any place in the winter time, they're going to see it apply again to their everyday. (post-teaching interview, record 127)

She can be seen, in these comments, as having been persuaded by teaching the unit that the "reduce content" side of the argument made sense *in terms of students' learning*. Her emphasis on being able to apply knowledge in real-world contexts placed her in the scientific literacy position on both subcategories of Goal 2, as well as the Strategies subcategory of Goal 1.

She still held on to a portion of the discipline-based conception of content, though. (Is it too good to be true that anyone can change their beliefs entirely by an experience that lasts only a few weeks? Of course it is.) She suggested that bright students probably need more than the amount of content addressed in the unit ("Some of these kids I think are a little bit beyond so I don't know if you need something, again to add to it that would be more...maybe challenging"). But she seems to have a new way to manage the dilemma, one that will allow her to teach less in order to teach for understanding: Slow down and take time to observe—this will help all students learn well enough to apply their understanding; but find ways to supplement units like this for the brighter, faster students.

What is very interesting in her reasoning for covering less content is her desire for students to know the subject well enough to be able to use it in their everyday lives. This is the essential element in the scientific literacy focus, and the theme of the next story.

Using real-world contexts in teaching science. While Ms. Preston focused more on slowing the pace of instruction to accommodate a kind of learning based in the phenomena of the world, Mr. Jordon and Ms. Fletcher found the idea compelling of simply using more phenomena, more real-world contexts in their teaching. This was the primary change for both of these discipline-based teachers (Goal 2: Real-world contexts, is shaded for both of these teachers).

Neither had articulated explicitly anything about real-world contexts in their pre- interviews (which accounts for why the table of Teachers' Positions has Ms. Fletcher's cell for Goal 2: Real-world contexts shaded, even though no change is apparent from the markings in the cell), although Ms. Fletcher may have been vaguely referring to the real world when she talked about the importance of being able to transfer what one learns to new "situations," and Mr. Jordon said "The more activities that I feel I can use with the students, again, that's my way of hopefully helping them to have fun and realize that science is an *everyday occurrence*" (italics added for emphasis). Either of these statements could be interpreted to mean something other than the grounding of science learning in real-world contexts. Yet Mr. Jordon and Ms. Fletcher were both enthusiastic about using real-world contexts in teaching, as shown in their post-teaching interviews.

Each had salient memories of specific real-world contexts used in the unit. Ms. Fletcher conducted seven of the nine activities that were based on significant real-world contexts, a higher percentage than any of the other teachers. (The table that summarizes classroom observations and shows these counts is on pp. 82-83.) She found the "Storm Door Problem" to be the most compelling activity in the unit[10]; she mentioned it several times as a key activity. She recounted in the post- interview how it brought out students' everyday knowledge and experiences:

> Ms. Fletcher: The storm door problem is wonderful, they went through it, they thought about it. They drew a lot on their prior knowledge, and most everyone had had an instance where this occurred, be it sticking their tongue on a popcycle, actually touching a door, you know, being told not to stick their tongues on the climbing bars on the playground. They all had experience with it and their answers were such... they really got into

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[10] She was, unfortunately, the only teacher to use this activity with her students. She was also the only teacher to do more than 50% of the literal program elements that contained real-world contexts.

filling those questions out and thinking about what was happening in that respect, so this was an excellent activity (post- interview, record 108)

She liked the level of engagement her students had with this problem ("they really got into filling those questions out and thinking about what was happening"). She attributed this level of thoughtfulness to the fact that this problem drew out their everyday experiences with the real world. It may be that she saw how her learning goal of "being able to understand those concepts so they can transfer it to other situations" could be realized in the Storm Door Problem and other activities that incorporate real-world contexts.

Mr. Jordon only used three of seven activities grounded in real-world contexts. Still, he mentioned several examples in his post- interview of phenomena or systems that he would incorporate into his own unit on matter and molecules. saying that real-world contexts were basically overlooked in his unit. He liked the student pages with the drawing of a pond in winter (showing some ice and some open water) that asked students to explain why you can skate on the ice (or walk on it), but not on the water.

Interviewer: How satisfied were you with what your students got out of the unit?

Mr. Jordon: I was very satisfied. Of the two and a half lessons that I covered...I ....using this again, when I pull some of this material and use some of it next year (I would probably use it with my matter and molecules instead of at the end of the year like I did this year), I think that actually some of the things... some of the points on some of the questions that it posses like the ice on the lake with the tree, you know that hand out, that I could definitely find a place for as more of a real life context in

> our unit. So that's probably where I would put it in. (post- interview, record 134)

Mr. Jordon added after the tape recorder was turned off that they have a pond in the back of his school that they could use for doing projects like measuring its temperature through the course of the year and watching as it melts and freezes.

He also mentioned using a refrigerator as the focus for a discussion: "How does a refrigerator work, what's happening with that process? I know when you think about it we take it for granted but it's a pretty sophisticated process" (post- interview, record 146). Both Mr. Jordon and Ms. Fletcher said that they would try to add more real-world contexts to their units in the future.

Both teachers had learning goals that were firmly in the middle position—teachers who strive to help students understand the subtleties of the disciplines in its own terms, the big ideas of science and their connections to one another, as well as the evidence and methods used to obtain it that support those ideas. What they saw in the unit's activities and methods was a way of helping students understand these big ideas *as they apply to the world around them.* A change like this, for discipline-based teachers, may be the first move toward a scientific literacy focus. It's not difficult for many content-oriented teachers to think of science as a means for explaining the world. Neither spoke of *applying* knowledge in their pre-teaching interviews, yet neither would have diminished the desirability of this if directly asked. It was simply the case that their curricula, their representations of the subject matter did not contain many (if any non-canonical) uses of the real-world. It simply may be that they have been using textbooks scrubbed clean of examples, and need to see how real-world contexts can be used as the basis for instruction.

To make something complex more understandable. Mr. Bowden was categorized as "moving toward" scientific literacy positions in several of the post- interview subcategories. One of those was Goal 1: Learning Goals.

He began the unit with scientific literacy goals for *some* of the content of his curriculum, primarily the environmental science units: He wanted his students to understand the content of environmental science deeply enough so they could make decisions about critical social and community issues—to understand the big ideas of environmental science and how they can be used to inform decisions. But he was squarely in the discipline-based position for his other earth science content—he never spoke of the "big ideas" of earth science—and for his science fair projects—where inquiry was done only to learn how to solve problems, not to learn content.

What he saw from teaching the unit was that "regular" content could be taught in such a way that it became "important" content. And that made him extremely excited.

> Mr. Bowden: I think it was magical, what you were seeing....I only saw a few times all year with this particular group. I see it all the time with my group but I wanted to do it with a more challenging group for you, cause you're not always going to get groups like mine—my group probably isn't even the norm, my own home room class—so I wanted to do it with more of a normal class like you saw, and the way they responded and reacted I only saw a couple of times all year, so I think the unit's a very big success.
>
> Interviewer: Good.
>
> Mr. Bowden: You can really pat yourself on the back.
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> Interviewer: Oh, thank you.

Mr. Bowden: I mean that.

Interviewer: Thank you.

Mr. Bowden: It was magical.

Interviewer: What do you think contributed to that?

Mr. Bowden: Well, it's the way you wrote it up, the way you made a very difficult subject very simple for kids to understand, for the teacher to understand, it was very... very easy... friendly for the teacher... teacher friendly. (post- interview, record 54)

He was excited about how successful he felt the unit was in making a complex subject simple, both by finding simple activities to illustrate complex phenomena, and by finding simple ways to talk with 5th graders about a deep subject. His statement "...you made a very difficult subject very simple for kids to understand..." shows his appreciation for *understanding* as a learning goal, especially understanding of a "very difficult subject," as most science concepts are. He indicates, with these comments, a shift in his position from not thinking much about the nature of "regular" content (where facts and definitions are usually undifferentiated from concepts, theories and applications) to recognizing that the content needs to be (and can be) articulated, demonstrated, and exemplified in ways that make it seem simple, in order to help students understand difficult subjects.

Dealing with student misconceptions. Several of the teachers in the study recognized, after using the unit, that another critical element in helping students make sense of science was the need to address misconceptions, or naive ideas. While none of the teachers talked about misconceptions in the pre-teaching interview, five out of six talked about misconceptions in the post-teaching interview[11]. The unit pointed out specific misconceptions that students often have when studying melting and freezing, including that molecules get hard when ice freezes, and that an ice cube weighs more than the puddle of water it melts into, because solids always weigh more than liquids.

Here is a sample of what teachers said about misconceptions, all from post-teaching interviews:

Interviewer: When they acted out the solids [students use their bodies to model molecules in solid ice and molecules in liquid water] I think that there's an instruction in the book that asks them to put their hands on each others' shoulders. Did they do that?

Ms. Estrada: Yea.

Interviewer: OK, not everybody that I've watched has done that.

Ms. Estrada: Oh, really, you mean, just the teachers didn't have them do it or the kids just didn't want to do it.

Interviewer: The teachers didn't have them do it. They just stood in a straight line.

Ms. Estrada: Oh, no, I had them grab onto each others' shoulders, that's what the directions said and I thought the directions were written well because it did prove a point that they were together, whereas liquids are not, so the kids could see that. That was the difference right there, the bond, so I think that needs to be emphasized. Because, you know, I think they could develop some misconceptions... yea, and I didn't get anybody screaming about I don't want to touch him or her. They were excited.

...

[11] The teacher who did not talk about misconceptions specifically said, in response to questioning, that he had not heard the term before.

Ms. Estrada: [talking about weaknesses of the unit] I don't think I saw possible misconceptions, about what teachers could find [in their students' thinking.]

Ms. Fletcher : Very much so, that to me was probably the strength of this, was the way it built those concepts of what was really happening to the molecules when the liquid... when the water started to freeze. And also, changing the misconception that water molecules are soft and squishy as compared to being hard. It's really solidifying for them that water molecules are the same whether it's in liquid or whether it's in a solid form, and that I think... that to me was the strength of this, was building those concepts and how it was referred back to in Lessons 6, 7, and 8.
Interviewer: So, you think it was the repetition that was helpful....
Ms. Fletcher : And also, the repetition was looked back upon but then built up on afterwards. You know as far as... for me Lesson 6 was the best and that's where a lot of the building of the concept occurred.
Interviewer: Do you see this as being different from other teaching materials that you use in this sense?
Ms. Fletcher : Definitely, most definitely, I mean I, of the science programs that we use, to me, a lot of it's done in isolation, there's not what I consider, good solid scientific information, but this did it.
Interviewer: Oh, good, well some people think there's not enough good solid scientific information available for the students in this unit.
Ms. Fletcher : Well, maybe I'm looking at it from the viewpoint of a fourth or fifth grader and I've taught from Kindergarten all the way to eighth grade science and the understanding that I feel my students are walking away with, with regards to the basic understanding of how water

becomes ice and what happens to the molecules, is very strong. Now I might be completely... you know, they might not be, but the discussion that I was getting from them and the information that I was getting them to share back with me was to me a good solid understanding of what was happening, and cleared up a lot of misconceptions.

...

Ms. Fletcher : So yes, there's a lot of misconceptions out there, but I think that this really solidified, you know, and I mean they may not get it right every time but the most part they've got a fairly good understanding.

Interviewer: On transparency 15, they're asked to pick one of these: When ice melts, its molecules: a) weigh less, because they melt into a puddle; b) weigh less, because liquids weigh less than solids; c) stay the same weight, but break apart from each other; d) weigh more, because the puddle they melt into is more dense than the ice cube.

Ms. Preston: See I think this is good because I think this will get them to say it's got to be more, its a solid.

Interviewer: It's solid, yes, 75 percent of students...

Ms. Preston: Have those misconceptions.

Interviewer: Yes.

Mr. Jordon: I use writing a lot in my social studies class, more of a problem solving approach to history than just memorization. So I like to see it in science as well. When you talk about writing, a lot of teachers... writing is taboo because they have to read it and correct it and a lot of teachers stay away from writing but I really see it as essential to giving students help. The best way in my opinion to have a student tell you what they know is to ask the right question and let them answer it and you can tell where the misconceptions are.

Even with all this talk about misconceptions, only Ms. Fletcher, who followed the lessons exactly as written, and Ms. VandenBerg, who practiced strategic teaching, used more than half of the opportunities in the unit to gain information about students' ideas. In all the teaching observed, only Ms. VandenBerg actually responded to naive statements made by students—one of the hallmarks of strategic teaching. She had a sense of *how* to use knowledge about students' developing understanding:

> Ms. VandenBerg: I don't think they actually realize how many actual experiments it takes to change a misconception, because when I was taking the SEMS workshop, to change a misconception in a first or second grader's mind, it takes 10 to 11 different activities to change that misconception. And I can believe it, you know, they still don't, as much as we repeated it and talked about it, they still weren't sure [about molecules not changing, just slowing down], so it just shows the more you do it, the more you find another way to do it or find something else similar, OK, but you have to keep going back and do differently what they had done before and show them that this is similar or this is the same concept only with a new approach.

The story-line teachers ignored naive responses rather than trying to reshape their questions or use different examples. They choose to pose their question to other students until someone gave the scientific response. In this way, story-line teachers never held individual students accountable for their ideas; only *someone* in the class, or the teacher, had to state the scientific response—the assumption being that having the scientific thought stated clearly in class sufficiently allows everyone to learn it.[12]

So what is the change brought about by using this unit? A simple change, but definitely towards the scientific literacy focus: Teachers begin to talk about misconceptions and naive thinking after using the unit. Why is this notable? Because all five of the teachers who found a place for misconceptions in their discourse about teaching—after using the unit—had attended workshops or seminars where misconceptions were talked about, prior to using the unit. Yet student thinking never came up in the pre-teaching interviews. Apparently, having information about student thinking and potential misconceptions in the unit stimulated their understanding of this subcategory. It moved them toward a position where knowledge of students is useful for strategic teaching, for developing scientific literacy.

One of the most interesting thoughts concerning this subcategory was voiced in the post- interviews by Mr. Jordon. He indicated that, if schools and teachers were really serious about helping students learn science, they would reduce class sizes considerably. Small classes would allow students to participate more fully in inquiries, and allow teachers to interact more directly with all students.

> Mr. Jordon: Ideally, if you have half that many [in a class], and they would be a small group, maybe a dozen to 15 kids, I think that would be ideal. But I don't think we'll ever necessarily see that unless it's done somehow through some sort of a teaming activity, where you've got multiple

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[12] This is also a more efficient approach to teaching, which is necessary when the teacher chooses to address what the discipline claims is important, rather than limiting the amount of what is taught in order to allow more time for making sense of it.

teacher teams and you can divide up your day in such a way that you can teach small groups. But we're not in my district at that point yet.

Interviewer: What would you see as some of the benefits for a group that size?

Mr. Jordon: Just being able to meet every child's need as far as inquiry. What happens in a larger class, and I saw episodes of that throughout the year in my class, was that a couple of students just pretty much dominate, and I know that there are other students out there that probably *had other ideas about what they were seeing or some concept of science* but because of the size of the group or because of the personalities of the class or maybe the personalities that they had to work with at that particular time, it inhibited them from really sharing their ideas and thoughts. And I think a big part of a small group would be to *help you identify with the children a little bit more differently and a little bit more intimately* than in a large group. (post- interview, record 144, italics added)

What he is indicating here is an approach to teaching that allows teachers to get closer to students' thinking, to "identify with the children a little bit more differently and a little bit more intimately." He's talking about an approach to teaching where students and teacher meet "mind to mind." This doesn't happen in story-line teaching, or activity-driven teaching. It is a critical part of the scientific literacy focus. The fact that these teachers recognized how misconceptions can interfere with students' understanding is a move toward this focus.

Learning new strategies. Two types of changes in "Goal 1: Strategies" positions have already been discussed: Ms. Preston's commitment to reducing content in order to teach for understanding, and Ms. VandenBerg's use of knowledge about students for addressing misconceptions. A weaker, but clearly noticeable effect of the unit on this subcategory was seen for Mr. Bowden and Mr. Jordon.

These two story-line teachers talked about a limited repertoire of teaching strategies in their pre-teaching interviews (as did all the teachers). But their repertoire, at least as they discussed it, was expanded by using the unit. In their post- interviews, they added new strategies that they believed were very important for teaching science, and that the unit made good use of: writing, using models, and using overhead transparencies for keeping students' attention focused.

Both teachers made clay models of how molecules are arranged in solids, as suggested by the unit, and used loose marbles to model the motion of molecules in liquids. Mr. Jordon was especially enamored of the unit's use of transparencies to state key questions. He believed that they focused students' attention better than if he used his voice to state a key question, mostly because, as he put it, "you know you have some kids that are pretty much on task, but especially when you [put] the kids in a science lab, they're always acting a little different, they're a little squirrly, and I think it maybe helps to draw their focus a little better" (post- interview, record 133). He also liked to use concept maps, which, he said, helped students "organize all the information in their head" so they can use it on problems they encountered later.

Both teachers also highly recommended using writing in science class, which was a major teaching strategy in *Hard As Ice*. Mr. Jordon stated that short answer or essay questions are much better for evaluating whether students know the concepts, not just whether they memorized answers. Mr. Bowden frequently gave assignments that asked students to write about what they've learned, or write about the procedure and results of experiments. He liked assessments that allowed students to write, because they really show what students know. Running through these comments can be seen a stronger disposition toward using strategies that encourage deep understanding, not just strategies that keep students engaged.

Science for *all* students: The underachiever. The specific issue having to do with Goal 3 (Promoting scientific literacy for *all* students) that most upper elementary teachers have to deal with is the issue of whether all students are capable of doing science, whether all students have the aptitude or the skills to succeed in science. While all students take science at these grade levels, and tracked classes are not an issue in most schools (not in any of these teachers' schools), the teachers in this study do notice that not all students participate to the same level, not all students express thoughtfulness and problem-solving ability at the same level. They know that girls are often told that "science is not for you, honey—leave it to the boys" and that boys often have more opportunities to participate in science related activities because of cultural stereotypes. Most of the teachers in this study expressed a desire to help *all* students see that science was fun and that they could succeed at it.

Three teachers specifically recognized the power of this unit for teaching *all* students, for bringing out their best understanding and their desire to participate. One could argue that this recognition moved these teachers from a belief that there are a few students who do not "have what it takes" to learn science (and who typically underachieve in many classes), to a position that science is, when taught well, accessible "even" to them.

This is how it played out in two classes, Mr. Bowden's and Ms. Estrada's. Both of these teachers regularly called on students who they knew did not always have the right answers (as they told the interviewer after classes).

Both expressed a desire to help groups of students succeed; Mr. Bowden said that he has helped many girls come to like science who start the year saying they hate it. In Mr. Bowden's school, "we teach a lot about diversity and respecting other people from day one" (pre- interview, record 47). These teachers are not unlike many teachers who go to extremes to help students who are not doing well in school.

In both of their classes there were several students who normally did not participate, who normally did not show their understanding in class or on tests, to the same level as the average student in the class. Those students sometimes required additional attention from the teacher because they would cause disruptions or misbehave in other ways.

In Mr. Bowden's class, one of these students was named Sarah[13]. Before Mr. Bowden mentioned anything about her, she appeared to the researcher to be one of three or four students who were answering most of the questions, and in her case, even posing some of her own. After one class, Mr. Bowden took the researcher aside and said: "Did you notice how Sarah has been? She has a very low IQ; in her other classes she mostly blows them off. My team teacher will tell you that about her! But in this unit she's been great!" In his post-teaching interview, he said, in explaining how "magical" this unit was: "The kids... I had kids in here that haven't responded like that all year, like that Sarah, so you hit on something here. When you can get kids like that!"

Ms. Estrada voiced the same idea:

Ms. Estrada: (continuing to talk about group work) Even my lowest kids were able to take more of the leadership position with being a facilitator or giving ideas.

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[13] A pseudonym.

Interviewer: Did that surprise you that even the lowest kids....

Ms. Estrada: No, not really, just because I've seen years of, for instance my special ed kids, are able to perform better in here because it's more hands on and they're not so....they're not afraid to take risks in here, and that's the kind of environment I try to create, where the kids are not afraid and when there is a conflict, we work it together so that child does not feel inhibited and being able to speak out because he's special ed, so it's taken a lot of work to get that, too, but then again, some of them just surprise me, they understand it really well. It's just a using a variety of different methods for them, whatever works for them. But... no I guess it didn't really surprise me at this level. At the beginning, when I first started doing this, I wasn't sure just how they were going to fit in here, you know, but they've really done well. But then again, they have the help of others which I think is so important that kids learn so much from each other, more than I can stand up there and tell them, they'll still get more out of helping each other and, like, I don't know if you noticed this boy in the class here, he tends to be a behavior problem but he was able to stay right there with the kids and even come up with some good ideas.

Even though she said she was not surprised when "the lowest kids" do well, she certainly seemed surprised about the boy she mentioned at the end of her quote. She may have been able to explain it, by saying that "it's taken a lot of work to get" to the point where students work well in groups and feel comfortable in her classroom environment, but still she seemed, if not surprised, then amazed, or grateful, or proud, just as Mr. Bowden was about Sarah. Mr. Bowden and Ms. Estrada were both amazed that two of the most difficult to reach of their students was more engaged, answered more questions, seemed smarter, seemed to understand the lessons better, than at times when they were not using the unit. This was a change in their attitude toward who can succeed.

Ms. Preston voiced her doubts that all students can learn science, in her post- interview, although in almost the same breath she reflected on how the unit and her teaching activities might combine to help the underachievers:

Ms. Preston: [They have to be able to] explain it to someone: [A student will say] "You know what I mean?" Well, yea, I know what you mean, but you explain it to me.

Interviewer: Were they able to do that without too much difficulty?

Ms. Preston: Yea, I think so, I think they did a good job in explaining.

Interviewer: Do you think there were some students who weren't as able to do it as others?

Ms. Preston: Well,.. I would guess that, yea, a little bit, but I'm not sure that those kids will ever be able to... I think that they probably are doing the best that they can. I don't... I just don't know... maybe they will, as we work toward having them write more and explain more, maybe they will be able to. I can pick out a couple of papers right here [she goes through her stack of papers]. Something like that [paper], it's not bad, but some of these, now this one should be real good but he's got a learning disability on his writing so what do you do? Now if you asked him [to say what he thinks, rather than write it]...

Interviewer: He's very good.

Ms. Preston: Very, very good. Some of these, I don't know how... I think that they understand what's going on but the writing part is hard for them.

Interviewer: So we might need alternative ways of getting them to show what they know.

Ms. Preston: I think the drawings are the main thing, we need to look at the drawings that they made on their papers, so I think that's probably the main thing there.

Ms. Preston's position is that some students will never be able to succeed in science, because, at least for some of them, their disabilities keep them from expressing themselves adequately. But she has seen, from the unit, that it may be possible to help those students develop to the point where they are as eloquent in their explanations as anyone else, by having them write and explain more, and by allowing them to use alternative means to express themselves, such as through drawings. As can be seen from the quote above, Ms. Preston changed her thinking about Goal 3 within a single breath.

<u>Summary of changes in teacher's positions</u>. The several stories described here show the effects on specific teachers of working with a new teaching unit that is intended to promote reform goals. These stories and their analyses show that different teachers, with varying constellations of positions and teaching approaches, learned different things from this unit, but did not come away from the experience with it untouched.

In summary, what did they learn, what decisions or commitments did they make, how have they changed? Table 8 (which displays the same data as Table 7) shows these changes, by adding short narrative about each change in the shaded cells.

On Goal 1: Promoting understanding over content coverage, one teacher, familiar with the reform issue of reducing content coverage but seeing it as a dilemma, made a decision that (for most students) her district's

Table 8
Teachers' Positions Highlighting Changes

	LV pre t'ing post	KB pre t'ing post	TF pre t'ing post	SJ pre t'ing post	FE pre t'ing post	JP* pre t'ing post
1: l'ing goals	▲ ■ ▲	▲ ▲ ▲■ simple ideas	▲ _ ▲	▲ _ ▲	▲ ❑ ▲	▲ _ ■❑
1: strate-gies	▲ ■ ■ writing etc., overcoming misc's	▲ ▲ ▲	▲ ▲ ▲	▲ ▲ ■ mind-to-mind, writing, OH	_ ❑ ❑	▲ _ ■ reducing amount of content
1: content knowl	■ ■ ■	▲ _ ■	▲ _ _	_ ▲ ▲	▲ _ _	■ _ ■
1: knl abt ss	▲ ■ ■ gaining & using	▲ ▲ ▲	_ ▲ ▲■ examples	_ _ ▲■ examples	▲ ▲ ▲■ examples	▲ _ ▲■ examples
2: imp act's	_ ■ ▲	■ _ ❑	■ ■ ■	_ ▲ _	_ ▲ ▲	_ _ ▲
2: r-w cntxts	▲ ▲ ▲	■ ❑ _	_ ■ ■ using	_ ▲ ■ using	_ _ _	_ _ ■
3: all ss	_ ■ ■	▲■ ■ ■ low achiever	_ ■ _	▲ _ ▲	▲ ■ ■ low achiever	❑ _ ■ low achiever
4: acr sci disc	_ ■ _	■ _ ■	_ _ _	_ _ _	_ _ ▲	_ _ _
4: other s-m	■ ■ ■	■ _ _	▲ ▲ _	_ ▲ ▲	■ ▲ ■	_ _ _
key:	❑ traditional	▲ discipline-based	■ scientific literacy	_ no information available	▲■ or ■❑ a mix of the two positions	shaded cells indicate sub-categories where changes occurred
	pre: from the pre-teaching interview	**t'ing**: from classroom observations	**post**: from the post-teaching interview		* JP was not observed.	

curriculum should limit the amount of content so that more time can be spent really exploring the phenomena and thinking deeply about it how to explain it.

Also on Goal 1, two teachers saw something about what it takes to develop an understanding of complex, difficult subjects: appropriate explanations, taught using appropriate activities, in learning settings where teacher and students can meet "mind-to-mind." Several teachers found new teaching strategies that helped their students understand the abstract ideas about molecules. Three teachers, who had all heard about misconceptions prior to teaching the unit, saw the value of helping students overcome their misconceptions, even if they did not routinely practice this in their observed teaching.

On Goal 2: Promoting science learning that is meaningful and relevant outside the classroom, two teachers changed their positions on the use of real-world contexts in teaching, from a discipline-based position that contexts are mostly "frosting on the cake" and canonical at best, to a scientific literacy position that science should be learned *in the context of* the real world.

On Goal 3: Promoting scientific literacy for *all* students, several teachers changed their minds about who can learn and who can succeed in science, coming more closely to the scientific literacy position that even those who normally have problems learning in traditional classes can learn science with appropriate teaching and support.

What about Goal 4: Promoting interdisciplinary learning? The fact is, most of the teachers in the study had a scientific literacy position before they began using the unit. What they saw in the unit that was interdisciplinary was in complete harmony with their own patterns of softening the boundaries between science fields, and using knowledge and skills from other subject areas in the learning of science. In fact, their statements about being interdisciplinary shaped the scientific literacy position on Goal 4. The exceptions were two of the three story line teachers: They said very little about being interdisciplinary; only after some coaxing would they say that perhaps mathematics might come into play in teaching science, and that writing was important.

Being ready. What do these learnings have in common? If there is a common thread that runs through them, it is that the teachers were somewhat familiar—prior to using the unit—with the positions they moved into. Many of these stories show that teachers who are already familiar with certain issues tend to have those issues sharpened for them in teaching with the new unit. Those teachers who had attended workshops on misconceptions saw concrete examples of them in teaching with the unit, and talked about the problems they can produce in learning. The story-line teachers who said they will bring more real-world contexts into their teaching undoubtedly knew that the disciplines of science were developed to explain and describe the real world, even if traditional textbooks did not include many such examples; they were given some permission to use real-world contexts as they should be used.

The teachers who saw understanding and involvement in the words and actions of the underachievers wanted to believe that all students can learn. While they certainly could not have missed hearing this slogan in the past decade, they saw it happen with their own students.

It should not be surprising that readiness is a component in adult learning. What implications this holds for overall professional development concerning the reforms that promote scientific literacy will be discussed in Chapter 5.

Findings concerning methodology

To establish the positions of teachers in this study, and search for changes in those positions during the course of using a new teaching unit, the researcher and his team worked with and refined methodology used in earlier studies of teachers' conceptions and their practice. Was the chosen methodology sufficiently useful for achieving the desired results?

Yes it was. The methodology gave good information for triangulating teachers' positions on the goal subcategories. The interview methodology was taken from the standard clinical interview procedure, where the interviewee is given some phenomenon, event, or system to consider, then asked to describe it, explain it, state his or her attitudes towards it, etc. In the case of this research, the interviewees were given aspects of teaching to consider, either from the unit itself or from their general practice, and their positions on goal subcategories was deduced from the statements about the unit and teaching. This worked well to elicit teachers' positions. The alternative procedure would be the political opinion survey research approach, where interviewees were asked direct questions about which candidates they favor and why, or where they stand on political issues, and their responses tallied directly. This alternative would not have worked with most teachers for eliciting their positions on reform issues, because directly asking their opinion on a statement of a reform goal does not get at the subtleties of their thinking. That is, asking teachers if they agree with "promoting understanding" or "promoting learning that is useful and relevant outside the classroom" almost always elicits a "yes" response, where no clear alternatives are stated. Even if clear alternatives are stated, such as "Do you believe that all students are capable of learning science, or that only those who are interested and smart enough can succeed?," chances are great that teachers will respond to the reform position, whether or not they believe in the details of that position.

Analysis of the interviews yielded, for most subcategories, sufficient data from which to deduce a position. The analysis approach was specific to this research, since statements made by the interviewees were categorized by goal subcategory, rather than directly using statements concerning the phenomena of the interview question. Explicit statements were eventually used in making sense of and reporting the results of the study, but the intermediate step of categorizing statements was specific to this research, and worked well for gathering the type of data desired (as it appears in Table 7, Teachers' Positions). To check the reliability of this step in the analysis, a second individual with strong understanding of the conceptual background of this study, but with no connection to the study itself, categorized a sample of records from the interview transcript data base, after appropriate training. 85% of the time the two coders chose the same passages in the interview segments to code, indicating that there was excellent agreement between the two on what passages in an interview segment contained pertinent information. 73% of the time the two coders chose the same code, or subcategory. For this type of coding, these reliability figures seemed sufficient.

The classroom observation method was borrowed from qualitative research on teachers' practice, and again was adapted to this study through the procedure of coding subcategories as they arose in the observation data. The analysis of the teaching data on some of the subcategories resulted in counts of occurrences, while on other subcategories the results were ratings of a teacher's position on that subcategory. Once again, sufficient data was derived from this procedure for triangulating teachers' positions along with the interview data. A reliability check was not conducted on this data, because of the method's similarity to that used with the interview data.

Student tests over the substance of the unit were administered to four of the six classes. The researcher did not anticipate using the results of the tests in substantial ways to corroborate data from the other two data sources, but they did confirm that a vast majority of students in all four classes learned what their teachers taught. The test data contains several types of information that is interesting to have in relation to some of the goal subcategories, such as information on teachers' effects on enduring misconceptions. However, it was not the intention of this study to determine the effectiveness of the teachers as they taught the unit, but rather the effects of the unit on teachers' positions.

In all, the interview methods and the classroom observations methods, including the procedures used for conducting both and the approaches to the analysis of their information, were sufficient for providing information on teachers positions on the reform goals. These methods complemented the conceptual framework for the study: The framework is based on a core assumption that teachers are rational decision-makers who have an ethical responsibility to their students. Similarly, the methods used allowed teachers the freedom to express their opinions and conduct their teaching as they desired.

Because of the satisfactory use of these methods in this study, the researcher feels confident that they would prove useful in other evaluation studies of interventions concerning the goals.

A deeper understanding of the goals

This study also resulted in a deeper understanding of the essential nature of scientific literacy. It illustrated and amplified the reform goals, in their depth of meaning and in the connections between them.

Their depth of meaning was explored in two ways as the conceptual framework (Table 5) was developed. First, each goal was analyzed into several key subcategories. These subcategories illuminate the goal by providing depth to it. "Goal 1: Understanding" was shown to have aspects to it that spanned over curriculum (learning goals), instruction (approaches & strategies), and teacher's knowledge (knowledge about content and knowledge about students). "Goal 2: Relevance" was shown to have aspects regarding the important activities in which students must become competent, as well as the contexts in which these activities occur. "Goal 3: *All* Students" was not broken into subcategories, although both the teacher's position on including all students, as well as some notion that actions must be taken to make this happen, is included in its description. "Goal 4: Interdisciplinary" was analyzed into two components, one that spanned the disciplines of science, and one that combined other subject area competencies with the teaching of science.

These subcategories allow deeper thinking about the goals by articulating each goal's "inner structure" (to use a metaphor from physical science). This structure assists in seeing the detail in the goals. For example, a deeper understanding of Goal 1 is gained by seeing how the fourth subcategory (Knowledge about students) works in tandem with the second subcategory (Teaching strategies). The two taken together illustrate a kind of teaching that strategically uses knowledge about students' thinking to design questions and activities that promote understanding.

Another example involves Goal 1 and Goal 2. The "Learning goals" subcategory of Goal 1 describes broad scientific literacy goals for student learning (using knowledge, constructing new knowledge, and reflecting on knowledge), while the "Important activities" subcategory of Goal 2 echoes these learning goals by describing the kinds of activities in which students must be engaged during class to develop scientific literacy (explaining, describing, predicting, designing, questioning, communicating, seeing connections, etc.) The Goal 4 subcategory of "Across other subject matter areas" also connects to these two subcategories, as they require being literate in the traditional sense, using mathematics when necessary to quantify scientific ideas, using science knowledge in tandem with economic and political knowledge to make community decisions, etc.

These essential connections across the goals not only help one understand each goal more deeply, but they show the connection between instruction and curriculum that is so often talked about. As can be seen in the conceptual framework, there are no subcategories called "curriculum," "instruction," or "assessment." Instead, all three are intertwined in the description of the four goals, indicating that scientific literacy is a set of competencies that are arrived at through the whole process of schooling.

The framework also illuminates the goals by providing authentic contrasts to them. The "discipline-based focus" and the "traditional focus" offer constellations of positions on the goals that are actually found in teaching and in teachers' discourse, and that provide a crisp contrast that highlights the essential nature of the scientific literacy positions. For example, while Goal 1 is stated as Promoting understanding over content coverage, the "discipline-based position" shows that there is an alternative somewhere between content coverage and the kind of understanding that scientific literacy strives for. It is an understanding of the "big ideas" of science and the evidence for them, although it is without regard for how those big ideas apply. It is a sophisticated but abstract and theoretical understanding of science, which highlights the need to apply or use knowledge in the scientific literacy position.

Another example is in "Goal 1: Knowledge about students." While a simple contrast would be between gaining and using knowledge of students' conceptions and not caring at all about what students think, the middle position indicates that many teachers do have some notions about what students know: Teachers learn over the course of years what students in their grade seem to be capable of learning, and what is too advanced or too easy for them. This "developmental knowledge" is generalized across all students, and usually relates more to topics than to what students specifically think about those topics. The scientific literacy position takes on more meaning when the "discipline-based" position as well as the "traditional" position are made clear. Other such contrasts can be seen throughout the conceptual framework.

For those researchers and practitioners who continue similar work, the analysis of the goals presented in the conceptual framework will be a valuable tool.

Summary of Chapter 4

Several sets of findings were presented in this chapter. They included conceptual contributions, empirical results, and methodological considerations.

The conceptual contributions were contained in the section on the Conceptual Framework of Positions on Goal Subcategories as well as the section titled "A deeper understanding of the goals." These sections consolidated various other research findings (as described in this chapter and in Chapter 2) and reform writings (also described in Chapter 2) to show how the reform goals could be further analyzed into several subcategories, and to show the range of positions possible on the reform goals and their subcategories. It showed how those positions tend to cluster into discrete and coherent orientations, not only around scientific literacy, but also around a strong discipline-based orientation, and a traditional orientation.

The empirical results showed the positions on reform goals of the six teachers in the study, and how those positions changed over the course of using a teaching unit designed to promote the goals. Several changes were noticed in the teachers in the study, often shared among two or more teachers. Changes were most noticeable in three subcategories of Goal 1: "Teachers' learning goals," where one teacher saw the importance of making a complex topic simple to learn; "Use of instructional strategies," where several teachers decided to use teaching approaches that would allow them to teach for greater depth of understanding; and "Knowledge about students," where several teachers saw how student misconceptions could interfere with learning. Also, changes were noted in one subcategory of Goal 2: "Real-world contexts," where two teachers decided they would connect their future teaching more to the phenomena and systems of the world; and Goal 3 (which has no subcategories) where several teachers recognized that students they previously thought could not succeed in science really could. These changes were meaningful and important to the teachers involved.

Several subcategories did not register changes. Goal 1: "Teachers' content knowledge," for instance, showed little change. Most of the teachers in the study had positions on Goal 4 which were either the goal positions or were not strongly challenged by the unit. The Goal 2: "Important activities" subcategory also saw no changes; what this might mean for future in-service professional development of teachers will be explored in Chapter 5.

The findings concerning methodology stated that the methods and procedures used to obtain data for this study were adequate for obtaining the kind of information desired in the proposal.

In the last chapter of this dissertation, the researcher will discuss what the results of this study mean in terms of the influence of teaching materials on reform efforts.

CHAPTER 5: SUMMARY AND IMPLICATIONS

This study examined the impact of newly-designed teaching materials on the views teachers hold about reform goals, particularly the goals for reform given in the *Michigan Essential Goals and Objectives for Science Education* (Michigan State Board of Education, 1991). The teaching materials consisted of one 5th-7th grade physical science unit (*Hard As Ice*), developed as part of the *New Directions Science Teaching Materials* series by the Michigan Department of Education. The units in this series were designed to exemplify the reform goals, and to provide teachers with knowledge needed to teach for scientific literacy.

This research is part of larger efforts to study ways to help teachers improve their practice. In particular, its purpose is to examine the role of curriculum materials as a strategy in reform efforts.

This study analyzed interviews with six upper elementary teachers to determine their views on reform goals, both before and after using the new curriculum materials. It also examined their teaching of the unit, and described ways in which their teaching embodied their reform positions. It looked for changes in their views that might be attributible to working with the instructional materials. This chapter looks back at the results of this inquiry, and attempts to draw conclusions from them. It also looks forward to the challenges of reform, and discusses some implications of this study for those challenges.

Learning from Teaching Materials: The Results of this Study

In this study, four specific research questions were addressed:

1) What positions do teachers take on new state and national goals for science education, and how do these positions change as the teachers use the *New Directions* teaching materials?
2) What kinds of practices occur in teachers' classrooms as they use the *New Directions* teaching materials?
3) How are those practices similar to or different from ones intended by the developers of the materials (intended to embody the reform goals), and how do the teachers view those deviations, especially in terms of their positions on the reform goals?
4) How are those practices similar to or different from the teachers' prior practices (as reported by the teachers), and how do teachers account for any changes in their practice?

Chapter 4 addressed these questions in some detail, revealing teachers' positions and practices as they were documented by classroom observations and pre-teaching and post-teaching interviews.

It was shown in Chapter 4 that teachers in this study held several different positions on state and national reform goals. It was also shown that their positions tend to cluster into identifiable patterns, or focuses. Three patterns were identified and described in the conceptual framework: the scientific literacy focus, the discipline-based focus, and the traditional focus. Each focus encompasses a number of interrelated positions on the goals, as seen from the perspective of the conceptual framework.

No individual espoused *all* of the positions in any one focus. However, the teachers could be identified as primarily being in one focus or another at the three distinct times when their positions were assessed (from the pre-teaching and post-teaching interviews, and from the classroom observations). Most of the teachers held positions that identified them with the discipline-based focus prior to using the unit. Three had approaches to teaching that were primarily discipline-based, while one conducted her teaching from a scientific literacy perspective, and one had strong indications of coming from a traditional focus in teaching (although with sophisticated techniques for conducting activities). From the post-interviews, one of the teachers (the one who demonstrated strong teaching for scientific literacy) had positions that were almost completely in the scientific literacy focus. Others provided evidence of being in scientific literacy positions on several goals (or at least they espoused positions that were leaning toward the scientific literacy position, or were a mix with the discipline-based position).

Even though the teachers can be described in general terms by the focuses, their positions on each of the goals and subcategories are complex and worth considering on a goal-by-goal basis. In fact, the descriptions about the changes seen during the course of this study actually did focus on specific goals, rather than teachers, even though some of the cases of change described in Chapter 4 were set in a context of an individual.

Considering, then, each goal, some broad results emerged. On Goals 3 and 4, teachers more often had scientific literacy positions: 64% of all positions taken—pre-teaching, from teaching, and post-teaching—were classified as scientific literacy, or had a strong scientific literacy component. But on Goals 1 and 2 the teachers had discipline-based or traditional focuses: only 41% of all positions taken were classified as scientific literacy, or had a strong scientific literacy component.

More specifically, on goal four, most of the teachers in the study believed in the reform position, feeling that their curriculum should be as interdisciplinary as possible. They would like to teach a curriculum that softens the boundaries between the disciplines of science as well as one that makes important connections to other subject matter areas. They appreciated the opportunities to do this within the units, on occasion, adding other interdisciplinary connections—but with the surprising caveat from two teachers that it is possible to lose some of the valuable time devoted to science by trying to address too much at once.

Teachers also generally held scientific literacy positions on goal three, believing that all students should and can learn science given appropriate support and appropriate approaches to teaching.

Looking at the changes in teachers' positions also reveals this difference between goals three and four, on one hand, and goals one and two on the other. Most of the changes seen during the course of the study were in goals one and two, rather than three or four, primarily because most of the teachers were already in scientific literacy positions on goals three and four (the exceptions were Mr. Jordon and Ms. Fletcher, who were the strongest discipline-based teachers). More changes were seen in goals one and two because teachers had farther to move on those two goals.

Why might scientific literacy positions be more common on Goals 3 and 4, and less common on Goals 1 and 2? Are there subtle characteristics of Goals 1 and 2 that might make them harder to reach than Goals 3 and 4? Looking more deeply at the subcategories, why might there be very few scientific literacy positions held on the subcategories of "Goal 1: Teachers learning goals" and "Goal 2: Important activities?"

One way to understand these differences is in terms of the knowledge teachers gained from using these materials. Of the changes on goals one and two seen in this study, most had to do with gaining knowledge about students' understanding, and learning strategies to teach more strategically. Four of the six teachers in the study gained knowledge of at least one persistent naive conception that students have about molecules and melting/freezing. While this is only one example, and few of the teachers devoted much teaching effort to *using* what they knew about this misconception, these changes show that teachers can learn from teaching materials that are designed to provide infomation about students' thinking. Four of the six teachers also added to their repertoire of teaching strategies as a result of working with these materials. All four recognized the central role of writing as a way of learning; they also found other strategies that would allow them to engage students' minds better and work more closely with individuals to ensure that each student developed ideas and competencies in the topic. This knowledge about pedagogy and knowledge about students' thinking are critical resources for teachers as they teach for conceptual change and scientific literacy.

This is an important outcome of this study: That teachers can gain essential knowledge from using curriculum materials. As Anderson and Smith (1987) argued, conceptual change teaching can be effective only when teachers have several types of knowledge: knowledge of the content, of strategies, and of students' thinking, as well as a general orientation toward teaching for conceptual change. The results of this study support the contention that teachers can gain some of this essential knowledge through their use of curriculum materials. Many of the changes in reform positions seen in this study were precisely this: teachers changed as they gained new knowledge, especially knowledge of students' thinking and of teaching strategies.

There appears to be a kind of knowledge that teachers did not gain well from their interaction with this unit, though, and it is related to content knowledge. While many of the teachers said they learned all the content they needed, they were apparently talking primarily about theoretical knowledge, knowledge about molecules and their arrangement and motion in solids and liquids. Mr. Bowden, for example, was highly enthusiastic about how this unit "made a complex subject simple." But he was talking about the complexities of unseeable and therefore abstract things—molecules. What seems to be missing from the content knowledge these teachers learned, then, is precisely what made Goals 1 and 2 so difficult for most of the teachers in the study to reach. It is the knowledge of how the theory applies to the world around us. Included with this knowledge is the disposition (or the learning goal) to *use* scientific knowledge as one deals with the world.

Teachers in general do not usually disagree with the statement that science education should teach students about the workings of the natural world, nor do they generally disagree with the statement that what one learns in school should be useful and relevant outside of school. But clear and explicit statements of this position were rarely voiced by the teachers in this study. More often, teachers would agree with the position that science education should promote understanding of important ideas and key concepts and de-emphasize memorization of isolated facts and definitions—but *the world outside the classroom* was rarely mentioned.

The challenge to all the teachers: Finding the core of scientific literacy. Mrs. Preston and Mr. Bowden were the only teachers in the study who talked about wanting their students to understand scientific knowledge in ways that it can be applied. More teachers talked about "challenging students to think" or getting them to really understand, without mentioning anything about real-world contexts that connect to their students' understanding or deep thinking. Thinking deeply, in their sense, apparently meant thinking about scientific theories and their connections within the realm of ideas, not their connections to the phenomena and systems of the world.

The position that appears to be most difficult to reach, then, seems to revolve around *using* scientific knowledge. Most of the teachers in the study had marvelous presentations of the content in the unit; one would even marvel at the competencies and collaboration shown in the "traditional focus" classroom as students did hands-on activities. The teachers' interactive presentations (or facilitation of activity-based science) were geared to helping students learn scientific knowledge in its own right, but did not necessarily help students learn how to use it to explain everyday phenomena.

What is challenging to teachers about the idea of using scientific knowledge? Certainly the notion of applying knowledge to solve problems (among other things) is in the general discourse related to learning science, and has been for decades. Is there something subtle, then, about this idea of using knowledge, that it is hidden in the unit, and hidden in the general discourse about reform, and therefore not reflected in most of the teachers' pre-, teaching, or post- positions?

For one thing, the idea of using scientific knowledge to explain how things work or to make decisions is not contained in the reform call that most teachers have heard. What most teachers have heard is that "hands-on, minds-on" science teaching is the approach for the nineties. This slogan is used to remind teachers that doing activities is not enough, that students need to think hard about those activities. This reform call has clearly gotten through to teachers (at least those in this study), either from everyday discourse about effective science teaching (as seen in the pre-teaching interviews and in many teachers' practice) or from the unit (probably from both). But "doing inquiry" and "thinking deeply" are contained in the discipline-based focus. They can be done with theoretical content knowledge only. They do not require knowledge of how theory connects to the real world. They are a *part* of scientific literacy, but not the whole; necessary, but not sufficient; not the core. They do not include *using* scientific knowledge in making decisions, or in understanding why something happens in the real world the way it does.

Another thing that makes the notion of using scientific knowledge subtle is that the ways in which it is used in this unit are mundane. They are not the kinds of issues that Mr. Bowden addressed in his curriculum having to do with important societal issues for which scientific knowledge could be helpful in making decisions. There were not the obvious contexts contained in such issues as the ethics of using bait to hunt bears (from Mr. Bowden's class), or the health and cleanliness of our drinking water. Instead they are contexts that may seem to the teachers to be intimately linked to the theory. Melting and freezing of ice on a pond seem intimately associated with the theoretical discussion of melting, to those of us who live with it in our everyday environment (most people in Michigan). This would be especially true in a unit where the only substance that students see melt or freeze is water.

This is where teachers' use of the unit became critical. Water is *not* the only substance that students could have seen melt or freeze. Lessons 9 and 10 have students observe the melting and freezing of other substances, and explain that in terms of molecules. But none of the teachers in the study did those lessons, and there was no indication that they read or considered them deeply enough to recognize that all of the substances dealt with in the unit were real world contexts to which scientific knowledge about molecules needs to be applied—even thought the introduction had several explicit statements about this. The teachers did not gain knowledge about how the theory could be applied, not from the introduction, and not from the lessons (certainly not from the ones they did not do).

Also, most of the teachers did not use the elements in the literal program that were intended to show students how the theoretical conceptions of molecules' motion and arrangement can be used to explain, for instance, the real world context of ice on ponds melting in the springtime. If they did not use these literal program elements, then there is good reason to believe that they do not focus on *using* scientific knowledge.

This relates to the link discussed in Chapter 4 between Goal 1: Teachers' Learning Goals and Goal 2: Important Activities. Most teachers in the study held the conception of science as an activity of developing theories and talking about them, and therefore saw the most important activity for students to be *explaining* content, not *using* it. This distinction is perhaps even more difficult because the reform rhetoric often uses the verb "to explain" in the sense of "explaining how phenomena of the real world work," which is not the same as the everyday sense of "explaining (explicating) abstract concepts." Perhaps the curriculum materials can be revised to make this distinction more evident. But other approaches to teacher learning may be needed to help teachers adopt this perspective on using scientific knowledge, and gain the additional knowledge needed to teach from it.

Moving to Scientific Literacy Positions: Implications for Teacher Learning

There is reason to believe, from what teachers in the study said (as mentioned in Chapter 4), that prior acquaintance with the issues contained in the goals may help teachers recognize and accept the goals. That is, where teachers in the study had heard about some aspect of the goals—such as the idea of misconceptions, or the notion that writing is a good thing in science, or the idea that "less is more"—they seemed to be able to pick up that emphasis from the unit and begin to accept it as their own position. Where teachers had some introduction to one of the goal positions, their use of the unit gave them concrete experiences in which they could see the ramifications of the goal position and "make it their own." While the professional development activity that introduced the teacher to the reform position did not, by itself, produce lasting change, it set the stage for the curriculum materials to bring the reforms into the classroom. In some way the professional development activity helped the teachers become ready to gain the particular knowledge that the curriculum materials were making available, to use it in their teaching, and to make it a part of their professional commitments.

<u>Developing support systems for teachers in the context of systemic change</u>. If teachers cannot adopt the most difficult position in the scientific literacy focus—using scientific knowledge—by using new materials alone, then a broader system of supports, a combination of efforts, may be needed. These efforts would be aimed at helping teachers enlarge their conceptions of science to include many more of the activities of real science that involve *using* scientific knowledge: describing phenomena, explaining how things work, making predictions about future events, designing tests of those predictions, designing and constructing things that work or diagnosing failure to work of machines and tools.

In fact, there is a fifth goal described in MEGOSE, but purposefully left out of the goal structure of the conceptual framework because, as mentioned earlier, it seemed to be of a different character. It now comes into play in this study. The fifth goal is about the need to develop support systems for teachers. While teaching from new curriculum materials may be a key element in a reform strategy because of the knowledge it can provide, other efforts need to be in place to introduce teachers to the goal positions and begin the teachers' internal deliberations.

Support systems can be broadly construed to include everything needed by teachers to teach. Curriculum materials are part of that system. So is the management of materials and equipment needed for conducting investigations. So is support from principals for "messy" science, support from parents for innovation, manageable class sizes, collegial relationships with other teachers that build a community of adult learners, reasonable daily schedules, assessments and evaluations that support teaching for conceptual change and scientific literacy, and worthwhile professional development. These supports are all elements of the education system that need to be aligned, that need to provide consistent signals to teachers about what is valued and respected in teaching. This sense of systemic reform, as described by Smith and O'Day (1991), increases the power of state education policy to make changes in the education of youth that are desired by the body politic.

It may be that the efficacy of curriculum materials for providing knowledge to teachers and encouraging new positions on reform would be enhanced through the establishment of curriculum networks, as proposed by Clune (1993). These networks—voluntary associations of educators connected by their professional interests—would be built around several coherent programs of school restructuring and curriculum revision. They would provide additional support to teachers who are implementing new curricula, by creating learning communities where teachers tease out the positions taken in materials, debate them, offer illustrations from their own teaching, and stimulate reflection. To some extent, perhaps, the interviews used in this study may have provided some element of this kind of reflection for teachers.

More traditional kinds of professional development activities may also be part of a system that would allow teachers to verbally process the ideas and consequences for teaching and learning that are behind the goals for scientific literacy. These activities would work in tandem with teachers' explorations of new positions as they actually teach with newly designed curriculum materials. They could have many different structures, and many different central tasks. For instances, they might include a review of achievement tests administered to students at the end of the unit and an examination of the test results, including planning for improving instruction in the areas of strong deficiencies. They could include observations of other teachers while they used the unit, demonstration teaching to those who intend to use the unit in the future, case studies of others who have undertaken the use of new materials, etc.

Future research. Indeed, if other types of support are needed to complement teaching with new materials as a way to improve science education, then the conceptual framework developed in this study can find application in research about this broader system of reform. The conceptual framework is a tool for understanding and describing teachers' positions on the goals for scientific literacy, one that can be used to highlight how teachers' positions may change over time, regardless of the activity that is intended to promote change: workshops, pilot testing, study groups, mentoring, etc.

But curriculum materials development and implementation is a strong strategy in the reform movement, perhaps even one of the cornerstones of the system of reform. Using newly designed materials is "action-research" for teachers, a learning experience that does not demand significant extra time from teachers outside of their normal daily tasks and that involves teachers directly in reform-oriented activities. It is a reform effort that has been shown here to be effective in some important ways. While it may be enhanced when combined with other reform efforts, it represents a means for teacher learning that is connected intimately with daily classroom life. Teachers can see the effects of new techniques and new approaches as they practice them.

Therefore, this study should inform continuing materials development efforts. One set of findings of this study concerned the difficulty of incorporating into one's teaching an orientation toward *using* scientific knowledge to explain how phenomena and events in the real world happen. Given that, future research and development efforts should focus on ways of making the distinction between explaining ideas and explaining phenomena clearer. It should focus on ways of giving prominence to those features of the literal program that call for the use of real-world contexts. It should focus on ways of contrasting those "important activities" of scientists that have to do with consequences of theories in the real world, predictions of events, application of knowledge in the design and control of systems, etc., with the examination of theory and its internal consistency and connections. That is not to say that these theory-oriented activities are inappropriate, only that they are a small part of the reform goals, a small part of what it means to be scientifically literate.

Curriculum materials can be more than repositories of factual knowledge, written at appropriate grade levels and organized by topics. They can be an important means for developing scientific literacy in students and conveying to teachers the knowledge they need to facilitate this development.

APPENDIX

APPENDIX

Literal program and summary of classroom observations

The complete literal program for Lessons 6 through 8 of *Hard As Ice* is listed in Table 9 below, along with the coding of each literal program element by goal subcategories from the conceptual framework. Abbreviations are used to reduce the size of the table. This table was used to summarize classroom observations by teacher, as shown for all observed lessons.

Table 9
Literal program for Lessons 6 – 8, *Hard As Ice*
and classroom observation summary

literal program element	goal sub-category	LV	KB	FE	TF	SJ
Lesson 6						
Part A: Students discuss as a class how ice and water are different, and speculate about what accounts for these differences.						
1 Set up problem for the lesson: *why* is ice different from water. Students handle samples.	2:r-w contexts	Lesson 6 not observed, but some items from this lesson were used in lesson 7, as noted	yes w/ mod.: "Why is ice hard but water flows." (1st)	Lesson 6 not observed, but teacher reported that students were very engaged	yes w/ mod.: "Why is ice hard but you can put your finger through water?"	no; students handle samples in 2
2 Have students list descriptive differences between ice and water, on board or **trans 4 (discussion)**	2:r-w contexts	yes (repeated in L7)	no		yes	yes; story-line questioning
3 Have students speculate about *why* ice is different from water (**trans 5**); draw out any ideas about molecules **(brainstorming and questioning)**	1:str's 1:k of ss 2:imp act's	yes (in L7)	yes (2nd); a		yes	yes; b

Table 9 (cont'd)

literal program element	goal sub-category	LV	KB	FE	TF	SJ
Part B: Teacher and students construct the molecular description of solids and liquids, using discussion, models, pictures, reading, and role-playing.						
4 Present the molecular explanation of solids and liquids (use picture on **trans 6**, clay model) (**lecture**)	1:t cont k 1:str's	made clay model	yes w/ mod., using sp9 instead; story-line; lack of cont k; un-responsive to naive conceptions (3rd); a		yes, did not use a model; b	yes w/ mod.: constructs with class, used two models, did not respond to naive ideas; b
5 Use bodies to make model; teacher points out salient differences (**activity**)	4:acr s-m	yes (in L7)	yes (5, beginning of day 2)		yes, w/ mod.: asks Ss to discuss	yes; b
6 Read **sp 6a and 6b (reading)**	4:acr s-m	yes, after freezing experiment of L7	yes (4)	no; passed out during L7 freezing activity, but ss never read it	yes, out loud, w/ ss taking turns	no; passed out but not used; explains freezing
Part C: Students use knowledge of molecules to 1) explain why you can skate on ice (not water) and swim in water (not ice), and 2) describe the inadequacies of "the brick analogy"						
7 Discuss as a group or work individually to answer questions on **sp 7a and 7b**, Ice on a Pond (5 questions; picture also on **trans 7**) (**writing**)	1:l'ing goal 1:str's 2:r-w contexts 2:imp act's 4:acr s-m		yes, pushing ss to think (6th); b		yes, in groups; missed naive statement; b	yes; did not address student's naive conceptions; b
8 Discuss what's wrong with stacked and heaped bricks as analogies to ice and water molecules, **trans 8** (**discussion**)	1:str's 1:k of ss		no		yes; students responded, but no debate or discussion; c	no

Table 9 (cont'd)

literal program element	goal sub-category	LV	KB	FE	TF	SJ
Lesson 7						
Part A: Students make ice, recording the temperature of water as it freezes and making careful observations of the freezing process.						
1 Have students set up the activity, construct a chart for recording data (**trans 9**), and conduct the experiment. (**activity**)	1:str's 2:imp act's 2:r-w contexts	yes; added a key Q; a; (l'ing goal:a)	no, because the activity was too difficult w/ other class; **not a**	yes; she created her own exp. design transp.; added same key Q as LV; c (soph. tech.) l'ing goal: c, processes	yes, controlling it but involving all students; b	yes w/ mod.: he controlled it; lack of ped. cont. k; b
Have students graph their results.	1:str's 4:acr s-m	no, because temp. never changed	(no, because it follows from 7-1)	yes	yes, w/ mod.: T does it; b	no
Discuss results of experiment (what they observed), using questions on **trans 9**. (**discussion**)	2:imp act's	yes, w/o t9, after students wrote about results in their journals	(no)	yes	yes	no
2 Do steps a-e of the "storm door problem" while ss wait (**sp 8a/8b**) (**reading and writing**)	1:k of ss 2:imp act's 2:r-w contexts 4:acr s-m	no (no time)	no	no	yes; a	no

Table 9 (cont'd)

literal program element	goal sub category	LV	KB	FE	TF	SJ
Part B: Teacher and students construct the molecular explanation of freezing.						
3 Ask students to give their own ideas about how ice freezes (**trans 10**). (**speculate**)	1:str's 1:k of ss 2:imp act's	yes; a	no	no; she was at a loss at the end of this act. to know what to do next; c	yes; b	no
4 Use a Chinese Checkers set to model the process of freezing, and ask directed questions to help students think through the analogy. (**teacher demo and discussion**)	1:str's	no (don't know why; class was on a role constructing an expl.)	no	no	yes; she mentions and corrects the naive idea that molecules get hard when substance freezes; b (k of ss: b)	no
5a Have students write their own explanations of freezing on **sp 9**. (**writing**)	1:k of ss 2:imp act's 4:acr s-m	yes, w/ mod.: just discussed	no	(no)	yes	no
5b Discuss student responses and coach as needed (**trans 11 on misc., opt**). (**discussion**)	1:str's 1:k of ss 1:t cont k 2:imp act's 4:acr s-m	yes, with reference to other science topic; also used t11 very effectively; a	no	(no)	yes, w/ mod. only used trans. 11, did not discuss or coach; c	no
5c Have students do **sp 10** as an extension (optional). (**writing**)	1:str's 2:r-w contexts	no (no time), but she mentioned pond in 7-1a	no	no	yes, w/ mod. done as HW, no discussion	no

Table 9 (cont'd)

literal program element	**goal sub-category**	**LV**	**KB**	**FE**	**TF**	**SJ**
Part C: Teacher and students construct the molecular explanation of melting.						
optional Melting experiment. **—OR—** Ask students to visualize ice as it melts.	1:str's	no	no	no	no	no
6 Have students develop an explanation of melting, using a set of directed questions **(sp 11)**. **(writing or discussion)**	1:str's 1:k of ss 2:imp act's 2:r-w contexts	no (no time)	yes w/ mod., after skipping all the freezing activities; did not use sp11. (7th); a	no	no	no
Lesson 8						
Solve the problem: Does an ice cube weigh more, less, or the same after it melts? Speculate, design an experiment, conduct it, and discuss.						
1. Show ice cube and melted ice, have students make predictions about weight and give their reasons. **(trans 12 or wall chart)**	1:k of ss 1:str's 2:imp act 2:r-w contexts 3	She did not have time to do this lesson. (She did lessons 1 through 7.)	yes, *all* students (8th, beginning of day 3); a	yes w/ mod.: first in groups, then a few mentioned in whole class; no real debate; c	yes; *all* students; a	He felt he did not have time to do this lesson.
2. Have students design an experiment (or use **trans 13**).	1:str's 2:imp act's		yes, as whole group; a, but did not respond to s proposed deviation from design in unit	yes; then compared their own design to trans. 13; c (soph. tech.)	no: gave them the design; b	
3. Have students conduct experiment.	1:str's		yes	yes	yes	

Table 9 (cont'd)

literal program element	**goal sub-category**	**LV**	**KB**	**FE**	**TF**	**SJ**
4. While waiting, have students draw "before and after" pictures of ice and the puddle it melts into.	1:k of ss 1:str's 2:imp act's		no	yes, but t did not check them; c	yes; c, no discussion	
5. Record the results for the class to view. (**wall chart**)			yes, w/ mod.: not recorded, only spoken	yes	yes	
Discuss how the results support their predictions.	1:str's 1:t cont k		yes; b	yes; b	yes, w/ mod. she tells them the conclusion; b	
6. Teacher and students construct an explanation of why there should be no weight change. (**trans 14, trans 15**)	1:str's 1:k of ss 2:imp act		yes; did not use trans. 14, promised to use trans. 15 next day (not observed); b (he eventually just told them)	yes, with mod. Did not use t14; had a s who knew the answer say it, told class to "write it down" w/o sign. disc.; c	yes w/ mod.: not in groups; used trans. 14 and 15; b	
7. Pose extension question about butter melting; debate and let students write.	1:k of ss 2:imp act 2:r-w contexts 4:acr s-m		no	no	no: asked ss to think about melting as homework	

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