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ABSTRACT

The findings reported in this paper are taken from the third phase of a multi-level examination of science and mathematics education reform in Michigan supported by the National Science Foundation (NSF) and known as the Michigan Statewide Systemic Initiative (MSSI). The third phase of the study seeks to learn what progress Michigan's teachers have made in understanding the reform ideas and putting them into practice in their classrooms. The questions that guide this study pertain to the nature of the science and mathematics curriculum taught in the state's public schools and how it is being taught, the reasons for the significant progress shown by some teachers toward the realization of the new standards for content and pedagogy, particular difficulties or obstacles with which those on the path to reform are struggling, and the suggestions implied by the data for reform-mined policy makers and professionals. Twelve teachers are profiled in the context of this study. Detailed information is provided within the paper about the results of classroom observations and interviews with these teachers. Contains 32 references. (DDR)

The Science Reforms: Mapping the Progress of Reform and Multiple Contexts of Influence

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INTRODUCTION

For about a decade, American scientists and science educators have been engaged in a sustained effort to define what our students should know and be able to do in their domain, as well as how knowledge of and about science should be taught. Though a variety of other important documents have appeared along the way, the general trajectory of the reform movement may be traced from the publication of AAAS' Science for All Americans in 1989, through NSTA's The Content Core in 1992, to the National Science Education Standards, put forward by the National Research Council just last year (1996). In our own state, the Michigan Essential Goals and Objectives for Science Education (MEGOSE) have been an important point of reference since their issuance by the State Board of Education in 1991.

There have been important differences among the documents, but most contemporary advocates of reform in science education urge the cultivation of "scientific literacy" for all students. By "scientific literacy," they refer not to mastery of facts and skills required to function at some rudimentary level, but to "an understanding of those aspects of science that are essential for full participation in a democratic society" (MEGOSE, p. 3) as a citizen, worker, and individual with a rewarding personal life. "Literacy" connotes a functional rather than an inert, school-bound conception of scientific knowledge, but not a narrow, mechanical, or pedestrian functionalism. The new science to be taught in school is a science of useful and used ideas, in the spirit of the remark that, "There is nothing so useful as a good theory."

The conception of content advanced in the new vision implies if it does not actually dictate an appropriate pedagogy, a pedagogy of learning science by doing science. Sometimes doing science may involve students in collecting data through "hands-on" activities. But whether students are generating new data or working with ideas and information presented by teachers and texts, they should be doing so in the context of a community whose norms enforce a discourse of evidence and civilized argument. And the efforts of the community are bent toward the construction of defensible knowledge, of ideas that can be used to describe, explain, and make predictions about physical, chemical, and biological phenomena and systems. The teacher's role is organizer and orchestrator of a miniature scientific community, establisher of norms, designer of tasks and an environment that supports individual and collaborative work on the tasks, provider of a scaffold for scientific novices. The teacher is the tribal elder who inducts students into the lore and ways of the tribe of science.

Some of these ideas about content and pedagogy resonate with major themes of an earlier wave of reform in science education, the famous curriculum development movement of the post-Sputnik era. But thanks to the past few decades' developments in the philosophy of science, cognitive psychology, and educational research, the conception of what it is to "do science" may be more sophisticated than in the earlier

movement, or at least than in the popular image of that movement. "Doing science" is conceived not simply or primarily as a matter of the overt physical activity of the student as s/he interacts with materials and equipment, but more importantly, of the mental activity that is represented through and shaped by the physical interaction, as well as the social activity or discourse through which students articulate, elaborate, and revise their understandings of the phenomena under investigation. The current wave of reform also displays a greater recognition of the role of the teacher and a more developed picture of the pedagogy required to structure and guide the "doing" of science in the classroom.

While these new ideas -- or sophistications of older ideas -- about the content and pedagogy of school science have been evolving, education policy makers at the federal and state levels have initiated a variety of activities designed to promote their realization in classrooms. The President and governors have made top international performance in science and mathematics a national goal. The National Science Foundation has awarded over $250 million in grants intended to focus and improve state level policies to support reforms. States have responded to the reform challenge with ideas of their own.

Though it is still very early in the process of reform, with typical American impatience, policy makers have begun to demand results. To us these demands seem premature. But it may be reasonable to ask more modestly, how is it going? What sort of progress are we making? What has proved difficult, and what obstacles have teachers encountered in trying to change their practice? What has proved helpful? What can both the progress we have made and the obstacles we have encountered teach education professionals and policy makers?

It is in this spirit of reflection on experience to date and hope to derive insights useful to policy makers and reform-minded professionals that we undertook the present study. Actually, the findings reported here come from the third phase of a multi-level examination of science and mathematics education reform in Michigan supported by the NSF-funded Michigan Statewide Systemic Initiative (MSSI). In the first phase, we examined the full range of state policies and programs that compose the policy environment for science and mathematics education in Michigan, both those specifically targeted to these subjects and general policies that seemed likely to affect them in important ways. We viewed the state policy environment against the proposals for "systemic reform" advanced by Smith & O'Day (Smith & O'Day, 1991 and O'Day and Smith, 1993). Smith & O'Day argued that states should (1) establish high standards for what all students should be expected to know and be able to do upon graduation, (2) align all key policies with the standards (e.g., those concerning curriculum and curricular materials, teacher education, professional development, assessment, and accountability systems), and (3) delegate increased responsibility to the individual school level for enabling students to meet the standards. Clune advocated a less centralized and standardized approach, relying on state endorsement and funding for "curriculum networks," each of which would set high but differing standards and help

schools that chose to join them to meet the standards. Though for several years the Michigan policy environment had been evolving or drifting in directions compatible with Smith & O'Day-style systemic reform, full realization of their proposal would have required the Governor and Legislature to vest far more authority and invest far more resources in the State Board and Department of Education than seemed likely to us at the time (Thompson, Spillane, and Cohen, 1994). Since then, the Governor has turned policy decisively in the direction of charter schools, schools of choice, and other market-based reforms, eclipsing or at least clouding the picture for systemic reform.

In the second phase of the study, we investigated policy and reform activity in nine local school districts strategically selected to vary on such dimensions as size; urban, suburban, or rural character; location in the state; reputation for reform-mindedness; and connections with MSSI. We found that all nine districts were engaged in some science and mathematics education reform activity, and virtually all had aligned the topics addressed in their district's curriculum with those in the state's curriculum documents, but only a few seemed to have fully grasped and begun to act upon the idea that reformers at both the state and national levels are calling not merely for a topical realignment of the curriculum, but for a thoroughgoing transformation of the substantive nature of the science and mathematics taught in schools and of the way that they are taught (Spillane, Thompson, et al, 1995). In our analysis, the key capacity required for districts to support such substantive realignment consists in administrators' and teacher leaders' ability to develop an understanding of the substantive ideas of transformative reform and to help others in the district learn them with understanding, as well.

As suggested above, in the present, third phase of the study we sought to learn what progress Michigan's teachers have made in understanding the reform ideas and putting them into practice in their classrooms. What is the nature of the science and mathematics now being taught in the state's public schools, and how is it being taught? Where teachers appear to have made significant progress toward realization of the new standards for content and pedagogy, what accounts for this? How did they come teach in reform-oriented ways? What particular difficulties and obstacles to more reform-oriented teaching are they and others who may not be so far along on the path to reform struggling with? And finally, what does all of this suggest that reform-minded policy makers and professionals might do to advance practice toward fuller realization of the reforms?

METHODS

In considering how to address these questions, we faced a now-familiar dilemma. Many prior studies of the introduction, adoption, and implementation of innovations have shown how misleading teachers' reports on their practice can be, not because teachers wish to mislead researchers (however many good reasons we may have given them to

do so), and not solely because the presumed social desirability of more innovative practices distorts their reports, but because they frequently misunderstand or only partially understand the practices they have been urged to implement, and thus believe that they are carrying out new ideas even when they are not. We wanted to create detailed and vivid pictures of practice, whether reformed or more traditional, pictures that taken together would reflect the current state of practice in convincing and memorable ways. These considerations argued for direct classroom observation, complemented by interviews tightly linked to the observations in order to hear teachers' interpretations of what and how they were teaching and of how they came to teach this content in these ways.

On the other hand, key policy makers in the reform movement, including some prominent advocates of systemic reform, have dismissed earlier case-based research on the progress of reform for employing such small samples. Yet the collection and analysis of qualitative data are notoriously expensive and time consuming. Even a well-known qualitative methodologist wrote of qualitative data as "an attractive nuisance" (Miles, 1979). Samples large enough to satisfy many quantitatively-oriented policy makers and researchers would be prohibitively expensive and morally daunting. So considerations of generalizability pushed us in the direction of survey methods.

Our resolution of this dilemma was to employ both survey and qualitative methods, but to do so strategically. We decided to use the Population 1 (3rd and 4th grade) and Population 2 (7th and 8th grade) teacher questionnaires from the Third International Mathematics and Science Study (TIMSS) as a basis for selecting a manageable sample of teachers to observe and interview. Obviously, the TIMSS questionnaire was not designed to measure progress toward realization of reforms in American science and mathematics education, but we were able to identify a set of items closely enough related to reform ideas to permit construction of reform scales in science, mathematics, and a combination of the two. We reasoned that while the TIMSS questionnaires might share the common tendency of questionnaires to produce responses that overestimate the implementation of innovative practices, teachers scoring high on our scale of reform orientation would be more reform oriented in their thinking and thus in their practice than teachers with lower reform scores. That is, the scale seemed a reasonable indicator of teachers' awareness and approval of reform-oriented ideas, and such awareness and approval seemed more likely to point toward reformed practice than would scores reflecting less awareness and endorsement of the reforms or outright rejection of them. (We will also use the TIMSS results for other purposes, but those will be pursued through other publications.)

Because we planned to link the three levels of our study in this and subsequent publications, we restricted our classroom level investigation to the districts examined in the second phase. We distributed the TIMSS questionnaire to all 640 elementary and middle school teachers of science and mathematics in the nine districts and, using

follow-up measures including an abbreviation of the questionnaire to the reform scale items alone, we obtained responses from 388 teachers, a return rate of 62 %. The questionnaire results will be reported separately.

On the basis of the reform scale results, we chose thirty two teachers to observe and interview, of whom 19 were elementary school teachers and 13 were middle school teachers. The elementary school teachers with a few exceptions taught both science and mathematics. Six of the middle school teachers taught science, and seven taught mathematics. We stratified the sample to ensure distribution across district types, locations within the state, and teachers who score high in science, mathematics, or both, then chose randomly from among the top-scoring teachers in each stratum. We observed and interviewed 16 elementary and 6 middle school teachers of science (See Table 1).

Using semistructured protocols, we observed and interviewed each teacher twice, with the exception of one teacher whom we observed only once due to scheduling difficulties. We frequently taped whole-class and small group discussions, and segments of these were incorporated into the observation reports. The report of each observation included background on the school, teacher, and class demographics, a narrative account of the lesson, and a copy of any worksheets or other materials distributed for teacher use. The interviews were transcribed. Reports and transcripts for teachers were then coded by categories corresponding to the characteristics of the content and pedagogy of the new science education, along with the categories "all students" (concerning issues of race, gender, class, and handicapping conditions) and "influences" (concerning the pressures, constraints, opportunities, and resources that shaped the teacher's practice).

As indicated previously, one of our major questions was whether and how the curricula and instructional approaches used by the teachers in our sample reflect the new vision of science education emerging at the national and state levels. Unlike the situation in mathematics education, however, in science there has been no single document that defines the new vision with generally accepted authority. Several efforts to define a new conception of science education appeared in the late eighties and early nineties, including Science for All Americans (Rutherford, AAAS, 1989), The Content Core: a Guide for Curriculum Developers (NSTA, 1992), and Michigan Essential Goals and Objectives for Science Education (K-12) (Michigan State Board of Education, 1991). Only recently have national standards for science education been issued (National Science Education Standards, National Research Council, 1996), and whether they will reach the level of acceptance achieved by the NCTM standards in mathematics is not yet clear. In any event, they had not been in place for long enough to have exerted any significant influence on practice. So it seemed somehow inappropriate to measure practice solely against the yardstick they offer.

Thus, the task of identifying the key features of the new vision against which to "measure" observed practice was not a straightforward one. Yet, although each of the efforts to define science standards used slightly different language and organized the ideas a bit differently, we discerned a reasonably coherent and consistent set of themes running through them. Thus, rather than simply choosing one of them, we created our own synthesis of the major themes. There are risks in this approach. Our version of the new vision does not correspond precisely to the version offered by any one of the standard-setting documents. Nevertheless, it did capture the main features of the new ideas about science content and pedagogy with sufficient comprehensiveness and fidelity to guide our observations and to structure our findings. A presentation of these features is integrated into the section on findings, below.

With respect to content, we concluded that the essence of the reforms has more to do with the nature of the knowledge and know-how that reformers want taught and to the way they want science as an enterprise to be characterized than with the particular topics specified for inclusion in the science curriculum. Our categories stressed the kind of knowledge teachers are dealing in and what kind of activity they portray science to be. There is a place for examining what topics are taught, but we think the reforms are much more about changing the kinds of knowledge that teachers and students are trafficking in than about which topics are taught at which grade levels. When content is viewed this way, it becomes very difficult to distinguish and separate content from pedagogy, or how the content is taught. For example, the best way to convey that scientific knowledge is usable and used knowledge may be to engage students in using it in nontrivial ways, and when a teacher does so, it is almost impossible to slip a conceptual scalpel between content and pedagogy. Many will argue that content and pedagogy should not and cannot be separated, and in several senses, we would agree. But for our purposes, it turned out to be useful to distinguish the two even while recognizing that in practice they are inseparable.

Using data coded with these categories, we prepared detailed analytic memoranda (ranging from about 40 to about 100 pages) on 17 teachers, and the vignettes and patterns of practice presented in the Findings section below were derived largely from these memoranda. Patterns derived from examination of the analytic memoranda were checked against the data for the remaining 5 teachers.

FINDINGS AND INTERPRETATION

As indicated in the foregoing section, for the qualitative study reported here, we chose 22 elementary and middle school teachers of science whose responses to the TIMSS questionnaire suggested that they were teaching these subjects in a manner generally consistent with the reforms. We reasoned that concentrating on teachers who seemed likely to be at the cutting edge of current practice should tell us how far along that advance guard is, what sorts of things they understand and do well, and where they

Table 1: SCIENCE TEACHERS OBSERVED AND INTERVIEWED
MSSI PHASE 3

Pseudonym	Gender	Educational Level	Major	Years of Service	School Level	District
Bach, Judy	Female	Bachelor Masters	Elementary teaching	5	Elementary	Pleasant Valley
Barry, Betsy	Female	Bachelor Masters	Health, Physical Ed. & Recreation Major. Biology Minor Physical Sciences	21	Middle	Steelton
Bedford, Karen	Female	Bachelors Masters plus hours	NA	20	Elementary	Redwood
Dingle, Nan	Female	Bachelors Masters	NA	8	Elementary	Pleasant Valley
Fond, Jane	Female	Bachelors Masters	NA	12	Middle	Parkwood
Glover, Joe	Male	Bachelors	Computer Science	20	Middle	Parkwood
Iben, Lynn	Female	Bachelors Masters	Education Language Arts	4	Elementary	Parkwood
Ingle, Karen	Female	Bachelors	Science Major, Teaching certificate for elementary	4	Middle	Pleasant Valley
Isaro, Nancy	Female	Bachelors Masters	Early Childhood Development (Major) Physical Ed. (Minor) Open Education	19	Elementary	Parkwood
Land, Darla	Female	Bachelors	Elementary Education, focus Mathematics	17	Elementary	Riverville
Lark, Isabel	Female	Bachelors	Elementary Education	30	Elementary	Redwood
Nelson, Emma	Female	Bachelors Masters	Education Science Middle Education	3	Middle	Pleasant Valley

Table 1: SCIENCE TEACHERS OBSERVED AND INTERVIEWED
MSSI PHASE 3

Pseudonym	Gender	Educational Level	Major	Years of Service	School Level	District
Newberry, Kathy	Female	Bachelors	Music	23	Elementary	Hamilton
Quant, Corinne	Female	Bachelors Masters	Education Early education	20	Elementary	Redwood
Sundmeir, Opal	Female	Bachelors Masters plus 60 hours	NA	19	Elementary	Parkwood
Townsend, Lori	Female	Bachelors Masters	NA	12	Elementary	Riverville
Turnby, Judy	Female	Bachelors Masters	NA	9	Elementary	Parkwood
Turner, Maria	Female	Bachelors	NA	26	Elementary	Redwood
Vargas, Iris	Female	Bachelors	Special Education	22	Elementary	Hamilton
Winston, Pam	Female	Bachelors	Home Economics, Child CareScience endorsement	15	Middle	Parkwood
Wright, Lisa	Female	Bachelors Masters	Compensatory Ed.	28	Elementary	Hamilton
Young, Margie	Female	Bachelors	Music	22	Elementary	Redwood

seem to be having difficulties in realizing the reforms. A best-case sample would also help us establish not a complete picture of where current practice stands in relation to the reform visions, but a sense of its upper limits. If many of the teachers in our sample had substantially realized the reforms in practice, then perhaps others were making good progress, as well, and might be expected to achieve fuller realization of reform ideas over the next few years. Conversely, if even the sample we chose because they reported practicing in reform-oriented ways had made little progress, then one might reasonably infer that there has been relatively little movement in the direction of the reforms among the broader population Michigan's teachers of science. Yet, even if observation and interviews of our best case sample were to imply worst-case conclusions concerning overall progress to date, perhaps the developmental experiences of teachers who are practicing in the most reform-oriented ways would suggest what reform-minded professionals and policy makers could do to promote progress on a broader front.

Unsurprisingly, few of the teachers in our sample had made substantial progress in transforming what they teach or how they teach along lines advocated by science and mathematics education reformers. Of the 22 elementary and middle school teachers of science in our sample, only 2 were teaching in generally reform-minded ways, and even these teachers had not fully integrated some of the most crucial features of the new teaching. Of the rest, many had made some changes in the surface features of their practice but did not seem to have grasped the core purposes that reformers intended these features to serve, and they were either practicing in quite traditional ways or had incorporated approaches that appeared innovative but which were unrelated to the reforms or downright contradictory to them.

This result is unsurprising because, as noted in the foregoing section, a comprehensive national consensus on what science should be taught and how it should be taught has been achieved quite recently, if at all. The National Science Education Standards were issued by the National Research Council only last year (1996), a month or two before we began data collection. Several of the key themes had been articulated in other reform documents, but the even earliest of these came out just before the turn of the present decade (Rutherford, AAAS, 1989). As many observers have noted (see Ball, 1996, see also, Wilson, Peterson, Ball & Cohen, 1996), to realize the reforms, most teachers would have to experience a thoroughly transformative learning process, both "unlearning" much of what they now know about science, teaching, and student learning and constructing more conceptually oriented, richly interconnected, and readily mobilized knowledge and know-how in all three domains. A great deal of research on prior efforts to change what is taught and how it is taught in America's schools has shown how resistant to change is this "technical core" of schooling (Goodlad, 1984; Cuban, 1993; Tyack and Cuban, 1995). Cohen (1995) has argued persuasively that the kernel of resistance is not to be found in political, organizational, or technical factors, but in the deeply embedded conceptions nearly all of us hold, conceptions of teaching as

telling, knowledge as facts, and learning as remembering. As we recently expressed the matter (Thompson and Zeuli, forthcoming), changing these deeply held beliefs is more like trying to unlearn a patellar reflex than like trying to learn a new route to work.

Thus, no one should be surprised that few teachers have revolutionized their practice in the past few years. These are deep and difficult changes to effect. Nor are we "bashing" teachers when we show how limited is the progress to date. Our purpose is not to join the strident chorus of criticism for schools and teachers, but to offer a dispassionate, arguably accurate account of where science education practice now stands in Michigan, and even more importantly, an account of how the teachers who are making progress have done so, and where they and some of their colleagues who are less advanced on the path of reform seem to be having difficulty. We turn now to a picture of where some of the more reform-oriented teachers in our sample do stand in relation to the reform vision.

Ms. Barry and the New Vision of Science Education

Having majored in health, physical education, and recreation and minored in biology at a state-supported university in a predominantly rural area of Michigan, Betsy Barry began her career as a "phys ed" teacher over 21 years ago. Later, she took a master's degree in health education at a similar university, as well as coursework roughly equivalent to a second master's degree in physical science. For several years, she has taught science at Rand Middle School, which is located on the outskirts of a small town and draws students from a wide rural compass. Her soft-spoken manner belied her self-described risk-taking, "Type A," personality:

> I've always been a risk-taker. So trying new things and falling on my face, I was able to cope with that part. You know I do that all the time, even now. ..... [I am a] Type A personality. Teaching the way I teach is difficult timewise. And this has sometimes been something I've been teased about.

Articulate and reflective, Ms. Barry saw herself as a learner whose hobby after a full day of teaching was teaching:

> ...It's just a personal choice. I put in a lot of overtime, and I always have. I throw myself into my career. It's like a hobby, I will work 2 to 4 hours overtime on an average day. And a lot of weekends. Because if you're going to set all these things up it takes a lot of time.

Of all the teachers in our sample, Ms. Barry came closest to a full realization of reformers' vision for science education, with respect both to what she taught and how she taught it. In the following subsections, we describe Ms. Barry's practice by comparing and contrasting it with reformers' vision for the new science education,

attempting simultaneously to give our exposition of the vision some concreteness with illustrations from Barry's teaching and to use the light of the new vision to throw features of Barry's teaching into relief. We highlight certain aspects of Barry's teaching in each subsection, but because dimensions that can be separated for purposes of analysis are intimately entangled in actual practice, the parsing is less than perfect. Thus, for example, examples of classroom practice reflecting the degree to which Barry engages students in constructing their own understandings of key ideas appear in several subsections in addition to the one devoted to "Scientific Activity: Using and Constructing Knowledge."

Fundamental, Connected Ideas

Rather than purveying the profusion of facts, skills, and terms that characterize the enacted curriculum in many classrooms, Barry preferred science education reformers' "fundamental ideas," ideas that have "rich explanatory power" concerning a "central event or phenomenon in the natural world," ideas that apply to "situations and contexts common to everyday experiences" (NSES, p. 109). Reformers' premise is that by concentrating on an economical set of key ideas that can be used to understand a variety of events, teachers can enable students to treat those ideas in sufficient depth to grasp and use them effectively.

A lesson from a unit on simple machines exemplified this emphasis on fundamental ideas. Earlier, Barry had introduced the concept of work, the product of force and distance. In small groups, students now were experimenting with levers constructed from Lego Dacta materials in order to determine the relationship between the length of a lever's effort arm and the force required to lift a given weight a certain distance. Asked about the activity she was engaged in, one student explained, "I'm trying to figure out ... how long the effort arm is, and the force needed to lift the weight." A little later, another student explained the meaning of the data she had recorded: "It takes more effort if the paper clips are closer to the fulcrum."

Barry's estimate of students' progress toward an understanding of levers reflected the kind of knowledge she sought to cultivate:

> What I feel for this class right now is that they have a definite feeling about the fulcrum, the effort force, the resistance work in the arms, and they have a feeling that all of these parts of the lever are going to occur. I think they're beginning to see that there are different kinds of levers. But of course I haven't given them enough information to really classify them yet. I think the concept of work right now is very much in its beginning with the class... They've understood everything we've done with work, but there's a lot of work -- a different kind of work -- to be done for myself and the students on this concept as it relates to the lever yet.

The unit on simple machines also exemplified the connectedness prized by reformers. According to reform proposals, a rich web of interconnections gives meaning to the fundamental ideas that scientific literacy comprises: "To understand an idea is to see how it is related to and supported by many other ideas; its meaning is bound up in those relationships" (NSES, p. 102). A particularly important form of interconnection is the composition of ideas into theoretical models or sets of propositions that can readily be used to explain or make predictions about new situations or new developments in systems that are under study. Reform documents also emphasize the importance of connections between ideas and real-world phenomena. A richly developed network of such connections makes it possible for the scientifically literate person to mobilize and employ the ideas nimbly and flexibly.

As Barry conceived it, the unit on simple machines was not just a collection of activities, one about levers, another about inclined planes, another about wedges, another about screws, and so on. Instead, it was a set of activities united by the underlying concept of work, with its constituent components of force and distance, and the way different machines provide mechanical advantage through manipulation of the relationship between force and distance. As Barry noted regarding levers:

> What they are moving toward as we bring these three together tomorrow is an understanding of the three different classes of levers. An understanding of the basic things that all levers have in common. And then to tie that in with the concept of work.

A passing remark about assessment in another unit suggested that this kind of connected conceptual thinking was habitual with Ms. Barry:

> So we were stressing conduction, convection and radiation. And a lot of these questions deal with these concepts. Put them in new, in new situations. So if I have five questions in there about convection I should see a common thread in their answers if they understand convection.

Barry also helped students connect the idea of work with a range of common tools, such as wheelbarrows, screwdrivers, pulleys, and the like.

Scientific Activity: Using and Constructing Knowledge

If the content of Barry's curriculum reflected key reform features, what of her pedagogy, of the way she tried to cultivate such knowledge? Consistent with other reform documents, the Michigan Essential Goals and Objectives for Science Education (MEGOSE) emphasize that science is something that people do, including three sorts of activities: using, constructing, and reflecting upon scientific knowledge. Students should

learn science primarily by engaging in these activities. They should use scientific knowledge to describe, explain, and predict phenomena, as well as to design new devices or systems. They should construct scientific knowledge by asking questions, seeking and interpreting new information represented in a variety of formats (e.g., tables, graphs), reasoning about it, solving problems, and reconstructing prior knowledge. And they should reflect on scientific knowledge. That is, they should step back and analyze it -- justifying it theoretically or empirically, making connections across different areas of knowledge, looking at it in historical and social context, and identifying the limits of both their own individual knowledge and scientific knowledge more generally.

The MEGOSE conception of learning through inquiry is consistent with the conception delineated in the NSES, going "...a step beyond 'science as a process,' in which students learn skills, such as observation, inference, and experimentation. The new vision ... requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking <u>to develop their understanding of science</u> (NSES, p. 105, emphasis added). Such a conception need not rule out presentations or reviews of key ideas by the teacher. Students generally need structure, guidance, and help in grasping the ideas and processes already generated by the larger scientific community. But as we shall see, the timing, function, and even the legitimacy of teacher presentations is debated by reform-oriented researchers in ways that call some of Barry's practices into question.

Barry did engage her students in using and constructing upon scientific knowledge, but with sometimes important limitations or departures from reform ideals. (Reflection on scientific knowledge is examined in a separate section below.) In the lesson on levers, for example, students used the terms and the concept of work introduced by Barry as they described what they were doing, collected data, and tried to account for the patterns in the data on the length of the effort arm and the force required to lift a standard load a certain distance. But Barry did not ask them before starting the activity to predict the results of this "experiment." The omission of prediction is far from trivial. As we shall see a little later, few of our teachers demonstrated a grasp of the nature and function of prediction in scientific work: to test the power of an underlying theory or model to account for the behavior of a system under investigation. Somewhat paradoxically, a remark Barry made about the contents of students' science journals suggests that she did understand prediction:

> So you would see a lot of observations from the students. You would find, uh, predictions. What they think. That they can go back and compare to after they've done some experimenting.

Why, then, did she omit prediction from the lesson on levers? Our analysis suggests that the omission was no accident, but is of a piece with a broader pattern in Barry's practice.

She tended to present important ideas before students began investigations or "experiments," rather than building toward such presentations (or even omitting them altogether) as many reform-oriented researchers would advocate.

Guidance and Facilitation within a Scientific Community

If scientific knowledge is socially constructed in communities governed by norms of discourse emphasizing logical argument and evidence, then by implication, the national and state standards argue, science education classrooms should also have the character of scientific communities where knowledge is, if not originally constructed, then certainly re-constructed by students engaged in processes of inquiry governed by norms of evidence and argument like those that govern full-fledged scientific communities. One of the teacher's primary functions is to establish scientific norms by modeling such behavior her/himself, by explicit instruction in how students should talk with each other as they carry out the kinds of activities outlined above, and by periodic reminders when the norms are broken and recognition when they are honored.

In the context of such a classroom community, the teacher is to guide and facilitate student learning. The image that emerges here is of students engaged in active, more or less self-directed inquiry which the teacher has framed by assigning an activity (see above) and which the teacher then shapes and structures as the inquiry unfolds. Providing "guidance" involves such things as clearing up students' confusion about purpose, what to do, and how to do it as well as keeping them on task and on track. Such guidance itself may be facilitating, but teachers should also interact with students during their investigations or problem-solving activities, generally asking substantive questions that prompt students to think, to explain, to reason out loud rather than giving them answers. Perhaps most important of all -- and, as we shall see, rarest of all as well -- the teacher should orchestrate discourse among the students themselves, sustained exchanges in which students articulate their interpretations of "experiments" or other hands-on activities and debate or discuss them, offering logical arguments and evidence for their views and revising their ideas when their peers offer persuasive reasons for doing so. Both teacher-student and student-student interactions should emphasize sense-making -- processing experience and information, developing or distilling understanding out of it, not just <u>having</u> the experience or memorizing information.

Barry's realization of this ideal of inquiry and discourse governed by the norms of a scientific community is impressive in some respects, but incomplete in others. She clearly understands the value and function of reflective discussion in helping students "build new ideas in their mind based on the evidence they have seen":

> . . . I have to constantly do a juggling act so that I can build in my times for reflection. Because to me that's where some of the real learning goes on is when they listened to each other. Had a chance to hear someone else's idea, challenge

> their own ideas, and start *to build new -- how would I put it -- new ideas in their mind based on the evidence that they have.* Because one of the things that I find constantly with this age group is that they are, they all have ideas on how things work. They carry these misconceptions with them. And they don't let go of them very easily. They need to see plenty of examples and talk to each other. (Emphasis ours.)

Thus, Barry sees "experiments" or hands-on activities not simply as motivational exercises or as experiences that are inherently educative without further processing, but as sources of evidence that students must discuss with each other in order to challenge existing misconceptions and "to build new ideas in their mind." This comprehension of discussion as a way of processing relatively unrefined experience into new understandings is, as we shall see later, exceedingly rare in our sample.

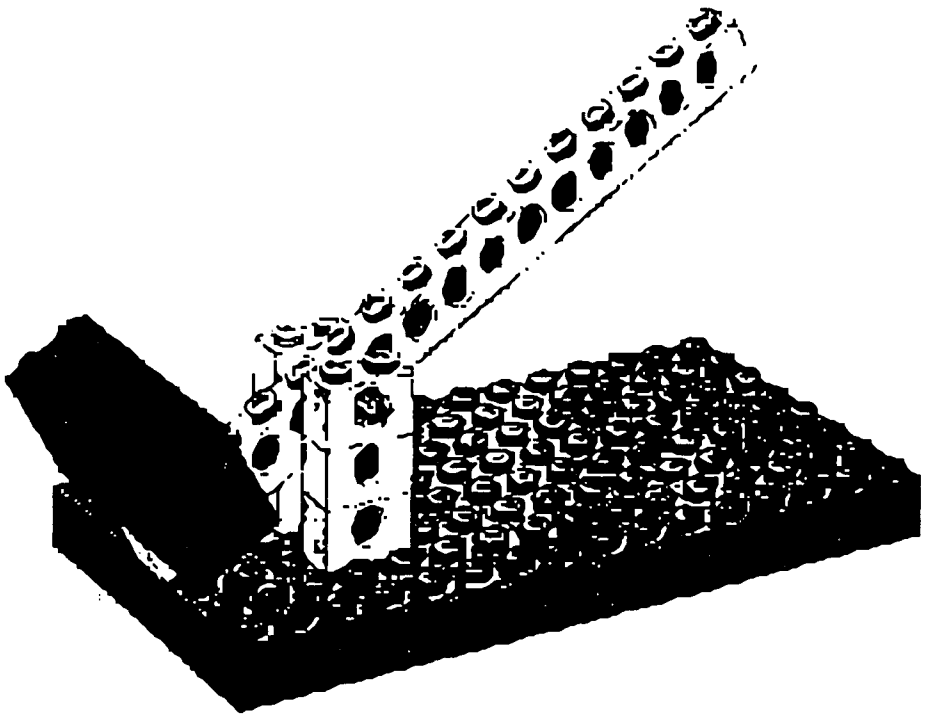
Nor, Barry claimed, is she the sole source of authority in the classroom:

> [T]hey talk to each other all the time and they don't look to the teacher to interpret anything for them. Or re-explain anything they've said. Or they don't look to the teacher to bail them out with another student who doesn't agree with them. So that the teacher is on their side. And that happens. "Oh, see, she thinks so, too." In those student-student interaction situations they have to control the whole tempo. And they also have to control what happens when everybody is just talking at once.

Barry's remark concerning "tempo," tossed off almost as an aside, turns out to be another crucial difference between her practice and that of most teachers in our sample. Discussions that are fully and carefully developed enough to enable students "to build new ideas in their mind" take time to unfold, far more time than most teachers in our sample seemed willing to invest. Even Barry sometimes cut discussion short before important opportunities for learning through discussion had been adequately exploited. But she more recognized the need to take time for the "extended investigations" proposed by reformers (NRC/NSES, 1996).

A segment of classroom discussion following up on the levers activity described above illustrates both the strengths and limitations of Barry's guidance and facilitation of discussions. Barry launched the session by asking for volunteers willing to share what they had learned from the lesson. One student said, quite ambiguously, "The closer the weight is to the fulcrum, the less weight you need to have." From the ensuing brief discussion among students, Ms. Barry seemed to conclude that more precise terminology might reduce confusion. She interrupted the discussion to hold up a model of one class of levers introduced the day before (see Figure 1 below) and asked if anyone could identify its parts.

Figure 1 Lever Model A



A volunteer came to the front of the class. Holding the model in her hand, she identified the fulcrum, the effort arm, the resistance arm, and the resistance (load). "I might have the resistance arm wrong," she hedged. This prompted a discussion of what the resistance arm is. After a brief dispute between two groups of students, each championing one or the other arm, Barry commented:

Ms. Barry: I'm not saying who is right, but I want to get you thinking.

Gary: Is it possible not to have a resistance arm?

Student: No.

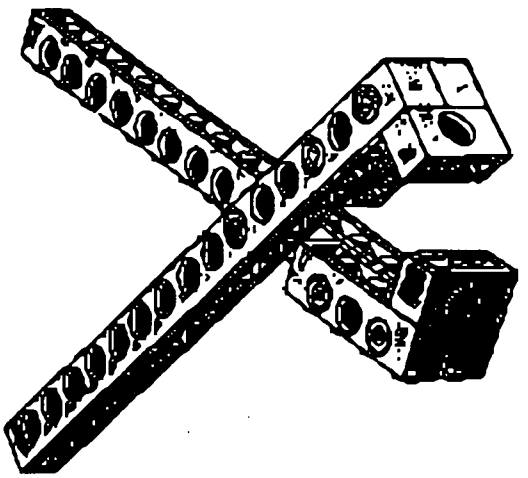
Ms. Barry: Why?

Gary: I can't see where the resistance arm is [on the model]

Ms. Barry: We'll do something shortly to see if we can answer that question.

Barry then held up a model of a different class of lever -- that is, a lever on which the resistance, fulcrum, and effort were distributed differently and asked students to identify the resistance arm on this model (see Figure 2, below).

Figure 2 - Lever Model B



Again, students disagreed. After several comments, Barry again intervened.

Ms. Barry: The question is posed is a good one. Are there both effort and resistance arms on this model? If so, where are they? What I want you to do is in your journal make a brief sketch of the model using these symbols: resistance, effort, fulcrum, effort arm, resistance arm, and use R, E, RA, F, and EA to identify these parts.

In many classrooms, this might have led to a simple matching exercise. But in Barry's classroom, the students did not seem to consider it such. They raised questions that suggested that they were thinking about the relationships between parts of the lever as they did their sketches. As students sketched, Barry told our observer, "This is how I know what students are thinking. They'll make their sketch and then I can see what each person is thinking. I'm not going to give them the answer. I'm not going to lay it out there." After circulating a bit, she said, "Draw the yellow model [a model of the class of lever depicted in Figure 2] because this is where you are having the problem." One student approached Ms. Barry with a question.

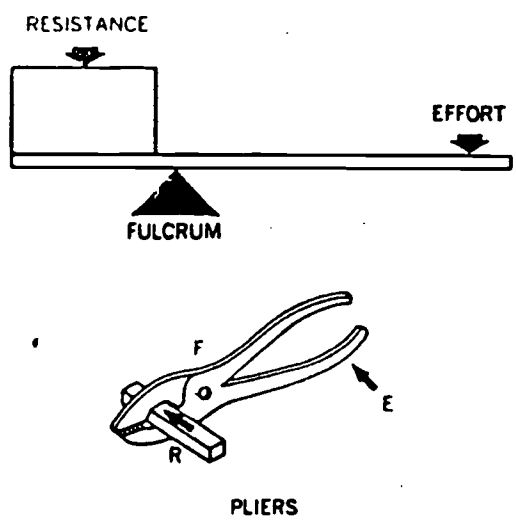
Ms. Barry: Nick has a valid question here. Come up and show [the class] what you are talking about. Say the things that you told me about how you changed the fulcrum and the effect of that.

Nick: The effort arm and the resistance arm can't be the same thing. . . [student's remarks become inaudible as he turns to manipulate the model]

Ms. Barry: The question is where is my effort arm? Is it different if the fulcrum is centered?

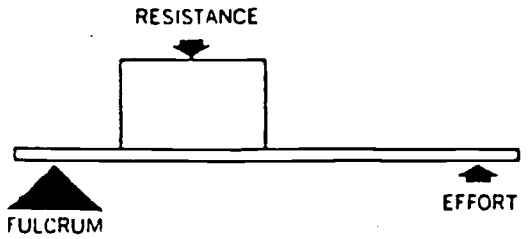
Rather than answering these questions directly, Barry then distributed an information sheet that described and illustrated the three classes of levers (See Figure 3 below). She asked each of three students to read one of the descriptions aloud to the class, beginning with levers of the first class.

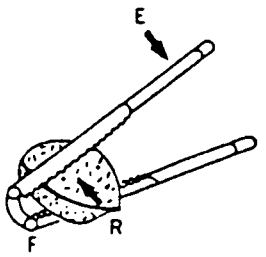
Figure 3 - Three Classes of Levers



Levers of the First Class

These levers change the direction of forces applied to it (sic) as they have a pivot point, fulcrum, between the two forces. Examples of levers of the first class include: scissors, pliers, crowbars, and a see-saw.

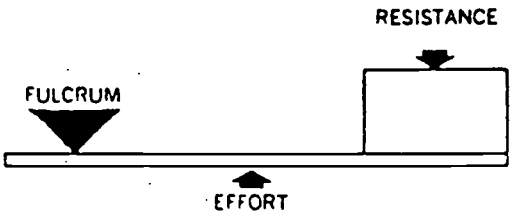


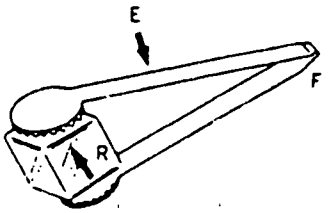


NUTCRACKER

Levers of the Second Class

These levers have the pivot point, fulcrum, at one end and the effort at the other end with the resistance in the middle. Examples include a door on a hinge, a nutcracker, wheelbarrow, oars of a rowboat, and a bottle opener.





ICE TONGS

Levers of the Third Class

Levers of the third class have the pivot point, fulcrum, at one end and the resistance on the other end with the effort in the middle. Examples include tweezers, ice tongs, baseball bat, shovels, and fishing poles.

After the information sheet was distributed and read aloud, Barry distributed a few tools to each small group or "team" of students. Each team was to identify its tools by the classes of levers they exemplified and then defend their identifications to the rest of the class. Among the tools were several not depicted or listed on the information sheet (e.g., hammer, egg cutter), as well as some that were. So again, this was not solely an exercise in matching given information, but required students to think about and explain the dynamics of each tool in terms of the schematizations of the dynamics of the three classes of levers. Thus students were using schemas that the teacher had provided them in order to understand the tools that Barry had distributed -- constructing, if you will, an understanding of each tool. But Barry gave students the schematics and textual explanations when she might rather easily have worked with the class to build the schematics, say, on the chalkboard or on an overhead. The teams might have been asked to make their own schematic drawings of the various tools, and these might have been put up on the board and discussed in whole-class mode before Barry introduced the conventional (and rather undescriptive) labels for the three classes of levers.

Nor, during the class session observed, did Barry return to Nick's puzzled rejection of the notion that the effort and resistance arms could be "the same thing." Nick's confusion was understandable, as the effort and resistance arms are physically different and separate components of levers of the first class, but lie along the same physical arm in the case of second and third class levers and can be separated only in a conceptual sense. For example, in levers of the second class, one might think of the whole arm as the effort arm, and only the segment from the fulcrum through the resistance as the resistance arm. Barry may have believed that the three schematics, once understood during the process of sorting the types of tools, would enable the students to sort this out for themselves. Or she may have returned to the question in a later class. But during this particular class session, she did not keep the discussion focused on the source of Nick's puzzlement until students were able to work out the solution for themselves. As in the case of the definition of work, Barry provided explanatory information for students to use, rather than leading them in constructing their own explanations -- a tightly circumscribed constructivism, if constructivism at all.

The ideal of the classroom as a miniature scientific community in which the teacher guides and facilitates student inquiry was more fully realized in another class session we observed. For this session, Ms. Barry had meticulously created an imaginary crime scene in the classroom. When entering the classroom, one saw on the other side of the room a 10′ long and 6′ wide piece of paper on which Barry had sketched the outline of a body and placed other evidence, including footprints, drinking glasses, a clock, a trail of red liquid, and other items. She said the crime scene was part of a "springboard activity" for a unit on genetics.

The activity involved a presumed murder committed against Felix, a millionaire who had recently purchased an expensive beach house and had thrown a weekend

housewarming party for four of his closest friends. One of the friends arrived to find Felix's body as outlined on the classroom crime scene, along with assorted evidence. The body was transported to the morgue but was then stolen. The students were the detectives and forensic scientists assigned to the case. Their' task was find out whether Felix is dead, and if so, who killed him. Barry gave them a description of the murder, permitted them to examine the crime scene, and later, provided detailed descriptions of the friends who had gathered at Felix's beach house to celebrate .

As Barry later explained, for her learning about science was not about "memorization," or "covering ground," but meant learning "how to think and solve a problem. How to know where to start.... [thinking] in a systematic way to solve it." She stressed the importance of making careful observations and analyzing evidence.

> One of the major goals from today's lessons, was, of course, to learn the difference between an observation and an inference. And one of the things that it will become apparent they've learned, but not apparent to them today, is the importance of careful observations..... Observations are one of the process skills of science that are at the heart of it. And evidence. Gathering and analyzing evidence, which is the next phase that they'll go into.

To begin the lesson we observed, Barry gave students a brief introduction, then allowed small groups of students to examine the crime scene closely. As they did so, students debated what they were seeing:

S1: There's some flour [looking near the ice cube tray].
S2: [No] That's water. [Looking at what's in the ice tray] Look at it.
S1: There is some flour there, or what looks like flour.
S3: There's chips of wood over here.
S2: This half [of the ice tray] is empty. Someone must have drunk it.
S1: Ken, people don't normally drink from the ice tray.
T: Two more minutes of observation.
S1: Ken, maybe it's sugar and not flour because sugar crystallizes like that.
[All the students kneel down to look carefully at the powder at the crime scene]

When all students had returned from the crime scene to their laboratory tables, Barry stood at the overhead. Written on one side of a transparency was, "Observations," on the other, "Inferences." After explaining the difference between the two, she asked students to offer their ideas.

S1: There was a clip-on earring. [Barry writes this under observation.]
S2: Three different types of footprints. One type was a dog, uh animal.
T: Why did you say animal?
S2: Possibly it's a dog.

T: That's an inference. In saying it's animal tracks, is that an observation or an inference? Any way you could be fooled?
S3: It could be a stick or something.
T: Did you hear that? Is it possible?
S4: Yes.
T: Should we put that as an observation or an inference?
S4: Inference.
T: Perhaps we could put, "Looks like animal tracks."
S5: There was also an outline of a dead guy.
T: What do you say about that?
S5: Some person. The person might not be dead.
S6: It might not be a guy.
S7: But the police don't trace them until they're dead.
T: I'll put a question mark behind that one.
S1: There were two pop cans, 2 glasses.
S8: How do you know it was pop?
T: What can we put down?
S9: Liquid.

As students attempted to identify items on the crime scene, taken for granted observations were regularly placed in abeyance; students recognized that they are drawing inferences instead of simply making an observation. Barry's was not a cookbook approach to the "scientific method." There was no generic process for students to follow in distinguishing between observations and inferences or in determining the relevance and validity of evidence. It was accomplished by *thinking* and *arguing* about specific evidence and its meaning. Though she stepped in at times and offered broad hints at others, Barry shared with her students the authority to separate observation from inference.

Critical Reflection within a Scientific Community

Later, Barry also discussed the notion of "pooling data" as a way for students to note discrepancies in what they observed. Referring to the lesson on the crime scene, she talked about the advantage of students examining the "data" (notes of observations from the crime scene) that other students had gathered:

> Those little pieces of notes that they've taken down, someone on the other side of the room might notice something you haven't, and it's going to be their job to realize that and learn that together. . . Even if they're doing the same investigation, I like to have them pool their data because it presents many instances where they can pick out discrepancies. They can pick out common threads. And to me that creates some of the interesting discussions and that is also situations where you find out about bias in your data.

Barry's concern about the warrant for claims -- about the accuracy of observations, the distinction between observation and inference, and the danger of bias -- and her use of civil argument among students, argument based on evidence and logic to decide the validity of claims distinguish her from the great majority of teachers in our sample. In this respect, Barry's practice very closely approximated the kind of critical reflection that reform documents hold up as an ideal.

It might be argued that Barry's use of the crime scene activity is flawed as a vehicle for communicating important ideas about the scientific process: students were engaged in constructing not a theoretical explanation of a natural phenomenon or designed system, but merely a valid narrative account of fictional events. Contemporary reformers generally urge teachers to embed the learning of procedural skills and knowledge within substantive investigations rather than removing them from the contexts in which they are commonly used. But as noted above, Barry employed the activity as a way of introducing a set of concepts that she planned to have students use in a unit on genetics. When asked about the relationship between the crime scene activity and the genetics unit, Barry said

> One of the pieces of evidence that they will be analyzing is DNA evidence from the hairs that are at the scene. And so they will look at the DNA fingerprints so to speak and match them. And then that will be my key to the genetics content that will follow. . . When they're doing their laboratory investigations and embedded in the investigation is content. . . you make inferences. You fill in gaps. You take in your old assumptions with you. And you use those to interpret the information . . . . And when you're going through a hundred and eighty days of schoolwork, sometimes you can get lax. Everybody can. The kids, the teachers Your observation, your inference, your real use of the content -- rather than just letting it go in one side and out the other -- is something that you have to try to keep fresh.

Thus, in Barry's view, the crime scene activity was a way to make vivid and "keep fresh" a concern for the warrant for claims.

Assessment as a Guide to Instruction

Science education reform documents argue that assessment should be virtually continuous, as teachers need to know what sense students are making of the central ideas addressed in a lesson ("understanding") and what they can do with these ideas ("ability") in order to adjust and reshape their own ongoing instructional behavior. The criticism of traditional practice embedded in this recommendation is that too many teachers fail to ask open-ended questions that allow students to demonstrate what they understand and misunderstand, assign worksheets that provide no feedback on what students are actually learning, and rely on tests largely to assign students grades rather

than to gain usable information on what they are learning. We have already seen Ms. Barry examine students' sketches of levers to pinpoint their confusions and use what she found to focus their investigation on a particular model of a lever. She reported that this kind of roving assessment was typical of her practice:

> I moved from group to group because this is where I find out what students are thinking. I ask a lot of questions, and I try to ask the questions that let me know if the, the understanding is coming across. As the students are working at their own pace and they're reading these questions sometimes the way they read them and the way they were intended might be different and I need to find that out. So, I, I'll ask them the same question in a different way. Throw some real stumpers in there in the lab paper. Which those are like my key questions where I can tell, "Okay, if they've got this question then they're really beginning to understand."

Partly as an assessment device and partly because she believed students learned by trying to articulate their reflections on activities from science class, Barry had the students keep journals of their work. "Journaling" was a fairly common practice among the teachers in our class, but the purpose of keeping a journal and the nature of its contents were not always so clearly substantive for other teachers as they were for Ms. Barry:

> . . . a lot of times we will have in a class period a question that might be the first question of a unit. What do you think causes this? Or I might give a short demonstration and the students would look at it and put their thoughts down. So you would see a lot of observations from the students. You would find, uh, predictions. What they think. That they can go back and compare to after they've done some experimenting. You would see experiment write ups and you would see responses to questions during labs like you see here. And then students do outside reading, you would find entries in the journal. . . . Pictures, lots of pictures, 'cause we sketch things.

Another intriguing aspect of Barry's assessment practice was her use of complex, open-ended "challenges" or problems to determine whether students understood key ideas in a usable way. For example, during the lessons we observed, students from other class periods sometimes came through Barry's classroom to check on how well their designs to prevent ice from melting or to keep fluids hot were working. As another way of testing students' understanding of heat, Barry had also given students a handout with questions like this: "Conductron is a new metal alloy that conducts heat better than copper. How would you test the validity of this advertising claim?" Ms Barry commented, ". . . there're many, many ways to answer that. But obviously, if they understand the process of conduction, which is one of the concepts, they will come up with something that relates to that." Whether Barry's challenges required actual

executing of a design, the formulation of an experiment to test a claim, or another mode of response, they consistently required the use of important scientific ideas in novel situations as a way of assessing her students' knowledge.

An Environment to Support Learning

Science reform documents call on teachers to "design and manage learning environments" that support learning through inquiry. They refer largely to the physical environment but also include the use of time. The teacher is to be a designer and manager of time, space, and resources. Ms. Barry's classroom reflected a learning environment conducive to students' investigation of scientific ideas. Students were engaged in extended investiations, the room was replete with different sorts of scientific materials used to support students' investigations, and there was evidence that students were involved in on-going projects that would foster their understanding, such as the designs to retain heat or to prevent ice from melting. Finally, in the two observed classes, Ms. Barry seemed to spare no effort in designing a learning environment that solicited students' active involvement with materials that were carefully chosen to foster their conceptual understanding of scientific ideas.

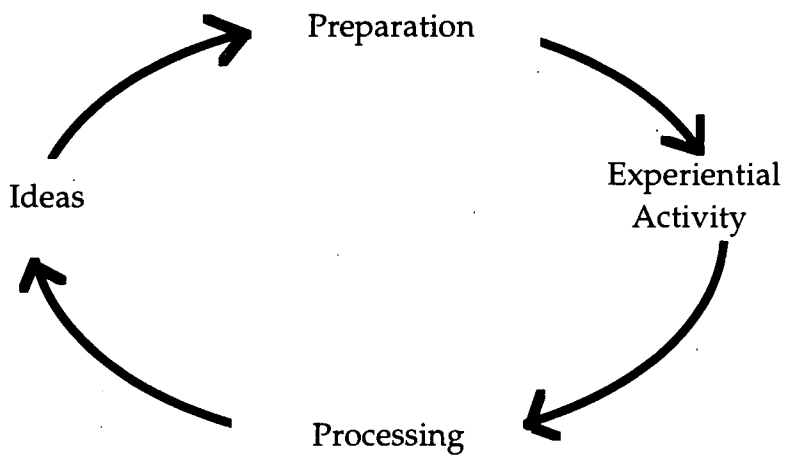
Reflections on Barry's Practice

In summary, then, Ms. Barry's practice approximated the reform ideal in many respects but fell short of it in significant ways. She taught a science of fundamental ideas, ideas that are connected with each other into theories and models, with natural phenomena and designed systems familiar from students' everyday lives, and with processes of scientific investigation. The activities she structured for students called on them to use these ideas for purposes of description, explanation, and design, as well as to reflect critically on the warrant for claims. She spoke with understanding about the nature and function of prediction in the conduct of scientific inquiry, but in the lessons we observed did not elicit students' predictions and their explanations of these predictions as a prelude to dissonance-inducing experiences -- did not exploit the pedagogical potential of prediction.

Though students' discussions may not have shown quite the full articulation of ideas or thorough elaboration of reasoning that reformers would like to see, Barry's classroom did resemble a miniature scientific community governed by norms of discourse emphasizing logical argument and evidence. But the extent to which students were engaged in actually constructing new conceptual understandings out of experience and evidence was circumscribed. In one lesson (about levers), Barry gave the students a conceptual explanation of work at the outset rather than engaging them first in investigations and discussions leading toward these ideas. In the other (crime scene), students were engaged in a more constructivist manner, but it was a valid narrative indicating "whodunit" rather than a conceptual explanation that they were involved in

constructing. In both cases, however, students had to use the ideas that Barry provided (about work in the one instance and about observation and inference in the other) in the context of an investigation, and we sensed that as they did so, students were beginning to develop a reasonably firm grasp of the distinction. Barry used a variety of means to track students' thinking (including their mis-thinking) and adjusted her instruction accordingly.

To sharpen our characterization of Barry's teaching and to set up comparisons between Barry's practice and that of others in our sample, the following simple scheme will be useful:



Barry tends to begin on the left, with the presentation of scientific ideas (e.g., the concept of work). Most science education reformers seem to prefer a cycle that starts with preparation for scientific activities (e.g., experiments, exploration), preparation that includes the posing of a substantive problem or question, the solicitation of students' predictions and their rationale for these, and an explanation not only of how to carry out the activity, but of how it bears on the substantive question under consideration.

Driver, for example (1994), argues for a sequence that runs roughly like this: the teacher poses a problem or questions regarding some phenomenon (light and shadow, for example). Knowing that students are likely already to have some ideas about the phenomenon, however naive or sophisticated these ideas may be, she then asks students to predict what will happen in a certain circumstance (e.g., whether an object's shadow on the wall will grow or shrink when a light source is moved closer to it) and even more importantly <u>why</u> this will happen. The various predictions and explanations are discussed, even argued over. Having drawn out and made explicit students' existing conceptions, then (and only then) the teacher proposes and students carry out an

experiment to test the predictions (e.g., the light source is actually moved closer to the object). The teacher knows in advance that many or most students' expectations will be spoiled. Indeed, inducing dissonance between students' prior conceptions and the observed outcomes of the experiment is a principal function of the experiment. Through questioning, the teacher orchestrates a discussion of the results. How might they be accounted for, and what new way of understanding the phenomenon can students suggest? After some discussion, the teacher would explain how scientists currently understand the phenomenon and answer students' questions about the scientific model. Then she would describe some new situation and ask for another round of predictions and explanations. These would subsequently be put to the test and the results discussed, and the cycle might be iterated. It is through these post-explanation predictions, experiments, and discussions that students come to appropriate and incorporate the scientific model into their cognitive repertoires.

Barry's approach can be viewed as a truncation of this model. In the lessons we observed, Barry did not begin with a problem or elicit students' naive theories, and did not seem to make clear to students exactly how the activity related to the ideas she had introduced. She seemed to proceed more or less directly to the presentation of a scientific concept (e.g., work) and model (work = force x distance), and then invite students to use the model to conceptualize and explain a system that they are manipulating. Interviews show that Barry is clearly aware of the existence and nature of students' misconceptions, and when confusions arose during or after the activities she assigned, she did promote student-student interaction to resolve them. But she did not launch lessons by to provoking and exploiting dissonance in the manner Driver advocates. She did guide students through activities that required that they use the ideas as they conducted the "experiment" and collected data. She also worked with students to process their experience and data by making drawings, writing in their journals, and most of all, through discussions in which she played a largely facilitative role. As we shall see, the presence or absence and the nature of these four elements -- preparation, experiential activities, processing, and ideas -- are crucial to whether and to what degree teachers realize the reform ideals in their practice. From the point of view of those ideals, the main flaws in Barry's teaching seem to occur in the overall sequencing and in the preparation phase.

Thus, it is a somewhat bounded constructivism that Barry practices, and if it is narrower than Driver's, it is perforce more circumscribed than the radical constructivism advocated by several other prominent researchers on children's thinking and learning about science (see, for example, Von Glazersfeld, 1990). Radical constructivists see the culminating moves in Driver's approach as short-circuiting students' rethinking of the phenomenon. They argue that in order to achieve genuine understanding, students must think their way all the way through to a new conceptualization. But Driver contends that, because scientific theories are complex intellectual inventions, not simple reflections of data or experience, students cannot be expected to construct many of them

entirely for themselves. Adhered to rigorously, her argument suggests, radical constructivism would mean the recapitulation of the history of science in every classroom -- even in every student. To Driver, this seems neither efficient nor consistent with the way science actually develops within the disciplines. At a certain key juncture in the learning process, the teacher should introduce an appropriate current scientific explanation, then help students construct an understanding of it through discussion and use.

So Barry's is far from a perfect realization of reform recommendations, but represents an impressive and instructive approximation. On the continuum from didactic to fully constructivist teaching proposed by Gallagher and Parker (unpublished manuscript, 1995), Barry's practice seems to fall near the middle, along the boundary between "conceptual" and "early constructivist" teaching. In conceptual teaching, content is organized around key ideas (rather than collections of facts and skills), but the teacher remains by far the dominant actor in the classroom, providing explanations, making the connections among key ideas and between key ideas and real world events, and telling or sometimes showing students how scientists come to know what they know. Hands-on activities are used to demonstrate ideas explained by the teacher. Most interaction is between the teacher and individual students, and interaction among students is generally limited to matters of procedure ("Is this what we're supposed to do?") rather than substance. The teacher checks for student ideas and uses what she learns to "correct" student misunderstandings. In early constructivist teaching, the content is also conceptual, but students play a more active role in constructing or reconstructing it for themselves, albeit with strong guidance form the teacher. Students' puzzlements and confusions about ideas introduced by the teacher are explored through discussions and investigations rather than simply corrected by the teacher. Discussions involve significant student-student interactions about substance, not merely about procedures. Assessment is used less to identify student errors to correct and more to surface students' ideas as a basis for discussion and further investigation.

Snapshots of Practice: an Album

As we have just seen, science education reformers argue that the primary purpose of assessment should not be to grade students, but to give teachers information about their students' evolving ideas, information that teachers can use to guide subsequent instruction. We view our own purpose analogously. Our purpose is not simply to "grade" teachers' progress in implementing the reforms, though in the next section we will provide a sense of the distribution of current practice in relation to the reform ideal. But more importantly, we have sought to develop and provide information on teachers' evolving ideas and practice for policy makers, professional developers, professors of pre-service teacher education, and others to use in reshaping their work. This implies that policy makers, along with professional developers and professors, are teachers, and indeed that is precisely our premise. As Cohen and Barnes (1993) have pointed out, all

meaningful policy requires some level of learning by those who are meant to implement it, and accordingly, policy makers might profitably view their own work as teaching rather than simply as regulating.

The information about students' thinking generated by even the best assessment does not tell teachers what to do. It simply illuminates their learners' state of mind. What their learners do and do not understand defines the challenge they face as teachers. Similarly, the information on teachers' practice that our research has generated does not tell policy makers, professional developers, or professors what to do, but it should help define the challenges they face as people who seek to teach teachers or influence them by other means.

Thus, although we begin this section with a teacher whose practice at its best approaches the level of Ms. Barry's and then work through an array of teaching practice that is progressively more distant from the reform ideals, our purpose is not to stand in judgment of teachers or display their shortcomings, but to show as vividly as we can where current practice stands and to relate some of what teachers say about why they are teaching as they do.

Ms. Ingle: Using Ideas, Hunting for Facts

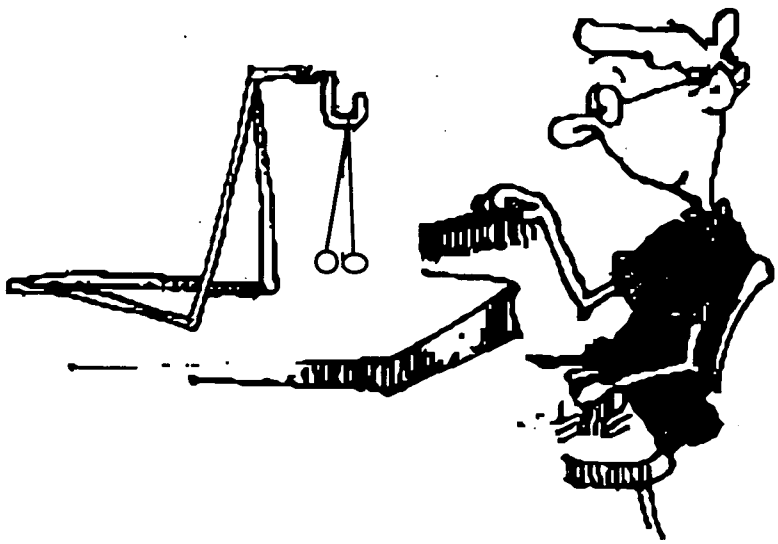
Ms. Ingle did most of her college coursework at a small Midwestern liberal arts college but finished at a larger regional university with a science major and teacher certification at the elementary level. After teaching briefly, she had "taken 15 years off" before returning to the profession. When we visited her, she was in her third year of teaching 7th grade science in a prosperous middle class neighborhood in a city dominated by scientifically oriented firms. Ingle's husband, a chemist, worked for one of them. The most reform-oriented slice of Ingle's practice that we observed was a "lab" on static electricity, a lab that she described as more highly "structured" than many she did. The session was held not in Ingle's regular classroom but in a science laboratory furnished with long black tables, surrounded by counters with sinks and experimental around the periphery. After some review of the previous day's lesson on magnetism and some procedural directions for the lab, Ingle said,

> "Now the last thing is, for you to be on the right track, what is your definition for static electricity? You're going to be exploring this, getting up close and personal with static electricity. What is the definition of static electricity? . . . If you can't remember, in your notebook, entry six has the definition. . . . Look it up. Use your references." She calls on a girl end encourages her to give the answer in her own words if she can; the girl says she can't and reads from her notebook.
>
> "The build-up of electrons on an object."

> "All right, the build-up of electrons on an object. That's static electricity. It's all in the electrons. So keep remembering that as you try to explain what is happening, as you try to observe static electricity." She asks whether there are any questions. The students seem eager to get under way with the activities and ask none.

At each of eight "stations" around the room were the directions and equipment for an activity. Students rotated among the stations in teams of three or four. At one of the tables, a group of students ran into difficulty with an activity which involved charging a comb by rubbing it with wool, then touching it carefully to one of two pith balls or rice puffs hanging side by side from a thread, as in the figure below:

Figure 4 - Static Electricity Activity



Though one student read the directions aloud to the rest, they proceeded with more enthusiasm, interest, and humor than precision. The two pith balls were not carefully lined up, and an extraneous piece of thread hung down beside them. They tried the "experiment" several times with a certain amount of fumbling and bumping, but grew frustrated as it did not seem to be working as advertised. Ingle's circulation around the class brought her to the frustrated group:

> The second boy says to her, "It doesn't repel. It just sticks." He shows her.
>
> "Okay, she says, "let's line these up so they're really side by side. And you've got a lot of extra thread here." She gets the scissors and snips off the extra thread. "Okay, so what's your problem?"

"They're not repelling," replies the girl. "They're just sticking together.

"Okay, so what are you observing? Are they doing anything?"

"They're just stickin' to the comb," says one of the boys.

"Okay," Ingle asks, what'd you do first of all?"

"Rubbed the comb."

"With what?"

"With this."

"Okay, with the wool. I'll give you a hint. Wool gives up electrons easily. So what's happening? So just explain it. So what's goin' on then?"

"It's generating static electricity," says the girl.

"Yes, but you can go deeper than that. When we rub the wool on this comb, what's happening?"

"You're charging this comb," says the boy who originally read the directions to the group.

"With?"

"Electrons."

"Electrons," Ingle agrees. "So what charge is that comb gonna have?"

"Negative charge," says the reader.

"Cause you've got a build-up of electrons. Do you know that?"

"Yeah, I know that. I'm just... slow," jokes the reader, to the girl's amusement."

"Now, move it over to the pith balls when it's charged... and, what happens?"

"It attracts," says the girl, with the kind of rising inflection many teenagers routinely use even when not asking a question.

"Does it?" Ingle asks. "I mean, it's like you're asking me."

"Um, it does," says the girl.

"So, it does attract. So they come together. Now, did you let the comb stay there for a little while?"

"When you're like, trying to pull it off," says the girl, demonstrating with the comb.

"Well, we did like this and..." the second boy recounts, demonstrating the procedure and fiddling the comb with both hands.

"What happens when you touch the comb all over with you hands?" Ingle asks. "It loses the electrons... the electrons run through your body. So get it charged up again....then... hold ... it ...next...to...your pith balls... " indicating the care that must be taken. "And see what happens. You said it attracts. Then let it sit there for a minute, and see what happens after that, and then try to explain what happens after that. If you observe something, then try to explain. You see what I'm saying?"

The girl nods.

"Only, you'll have to do it quickly because we're going to be switching. Understand?

"No," says the boy.

"Okay," Ingle says, "you charged your comb. What's the charge of your comb?"

"Negative."

"It's negative. Okay, you're bringing it up (indicates that the comb is near the pith balls) and you've got an attraction. Okay, why?"

"Because, says the girl, "negative (indicates comb)... positive (indicates pith balls).

"Okay," Ingle says, now, I'm telling you that if you held it here long enough, you'd see somethin' really neat happen. And maybe you're not gonna have time..."

"They repel?" asks the girl.

"What happens? What do you think happens?"

> "The charge... um, they charge each other?"
>
> "Excellent. And so if I stood here and held this, what would happen? If I held this long enough, they jump. They jump apart. Whoops! There they go. Now they're coming back. Now, what you're trying to do is to explain on paper what you just said to me. You said it well."

Several features of this episode are worth remarking. First, in terms of the cycle discussed above, Ingle's preparation for the activity was conceptual as well as procedural, but as Barry typically did, Ingle gave the main idea to the class early in the session (or had them extract it from their notebooks). She did not begin by posing a problem or question to elicit students' existing ideas in order to play these ideas off against data and experience derived from the activities. Further, at some junctures during the interaction, she injected her own ideas. Ingle was aware of this tendency and claimed to be struggling against it: ". . . something that I work on a lot is, I'd like to talk less. . . . I keep wanting to get more concise in what I say. And then, keep saving up more experiences that kids can do and experience it, or share it with each other. . . . I'm really content oriented, and I have to keep working at not giving answers. There are times when it's so bad, I wanna tell 'em, 'Oh, but it's this way!'"

Second, the episode illustrates that successful performance of the kinds of activities envisioned by reformers is far from automatic. Ingle may have tried on previous occasions to impress the need for precision upon the students, but the careful sequential action required for successful execution of the activities is not the natural mode of behavior for many students and seems difficult to inculcate. The rather breezy directions, taken from a booklet by a small innovative publisher that Ingle discovered on her own, did not reflect a recognition of this problem.

Third, the students seemed more interested in making the experiment "work" than in explaining their observations. This orientation was even more striking at another station involving the use of a static electricity generator:

> The group at the static generator was fascinated by the arc of sparks it created. Completely ignoring Ingle's repeated cautions, they try wider and wider gaps, creating longer and longer arcs. Periodically, one boy remembers that they are supposed to explain "why it happens." But they are repeatedly diverted by the phenomenon itself. They start to try to explain, but cannot resist trying the generator again and again.

Several researchers have pointed out that students engage with science activities in a variety of ways other than as scientists interesting in grasping the dynamics underlying the phenomenon. Schauble (1991), for example, has shown that students frequently act

more like engineers trying to produce a certain result than like scientists dedicated to understanding a phenomenon. Rath and Brown (1996) and have identified six common modes of student engagement, including exploration (getting a sense of an object's basic properties), engineering (using knowledge of phenomenon or system to making something happen), pet care (nurturing), procedural (step-following), performance (getting attention through use of the object), and fantasy (imaginative play with phenomenon). Whether and to what degree these various forms of engagement are or can be valuable is debatable (Brown, Beck, Frazier, and Rath,1996), but it seems safe to say that none of them is, by itself, quite the kind of "scientific activity" that reformers appear to have in mind.

Fourth, Ingle might have made the fact that the activity wasn't working out as designed a subject for reflection and investigation in itself, but she tried instead to correct the way students had carried out the activity in order to get it to "work" (e.g., snipped the thread, told how handling the comb could discharge it). Her approach appeared to be shaped by the need to attend to several groups of students simultaneously and perhaps by a general concern to maintain a pace that would enable her to "cover" the curriculum. Whatever its source, the felt need to maintain what often seemed a hurried pace worked against the "extended investigations" recommended by reformers.

Fifth, perhaps in her hurry, Ingle accepted a student's assertion that the pith balls were attracted to the comb because they were positively charged. On the face of it, there was no reason to assume that the balls were anything but neutral, and the reasons for the attraction are complex, involving the migration of electrons that are loosely held by the large organic molecules composing the rice pith balls. There are indications from an interaction Ingle had with another group, working with soap bubbles, that she probably did understand the dynamics of the phenomenon but seems to have had too many different things to attend to at the time to pay close attention to the details of what the student was arguing. A different lesson design -- say, one in which all small groups worked on the same activity in parallel -- might have made the cognitive load manageable, but it is worth noting that on-the-fly scientific analysis with many different students is extremely complex and demanding for the teacher. A good analogy might be with the chess matches that grand masters sometimes play against many opponents at once.

Sixth, the really substantive interaction in the episode was exclusively between Ingle and individual students rather than among the students. This pattern held across the five small group activities that were observed. Thus, at least in this session, Ingle's classroom did not convey the sense of scientific community governed by norms of evidence and argument that seemed to characterize Barry's classroom. In a follow-up interview, Ingle reported that the next day's session had been devoted to a discussion in which students compared their observations at the various stations, both attempting to explain what had gone wrong in their conduct of some of the "experiments" and attempting to explain

what they did observe. But we were unable to confirm her report with direct observation.

Seventh and finally, despite all of these problems, Ingle did structure and facilitate a lesson that engaged many students in using scientific ideas to understand phenomena or systems with which they had first-hand experience through intriguing activities. Though their mode of engagement with the activities varied, students did get "up close and personal" with static electricity, and Ingle was frequently able to provoke and support real thought about just what was going on below the surface of the phenomena. Her questioning was patient, polite, and impressively persistent -- "Yes, but you can go deeper than that." The problems in the lesson show just how difficult reform-oriented practice is to pull off; even a teacher who seems to understand many of the key reform ideas and who works hard at realizing them still has a ways to go.

Curiously, the other lesson of Ingle's that we observed was designed to be lively and "fun," but focused exclusively on isolated, even deliberately obscure facts rather than on scientific ideas. The activity was a "scavenger hunt" for weather-related facts employing varied sources in the library. Students were required to use at least 7 different sources to answer the 12 factual questions posed on a worksheet. Ingle's rationale for the lesson was that information retrieval skills are crucial in an era when the totality of information is overwhelming:

> R: Today's [lesson] -- that's more. . . those process skills -- how are you going to find out when you don't know something . . . . I just heard Everett Koop, the former surgeon general. I just heard him speak and . . . he's just saying that this is a drastic change, but our doctors that we are training, . . . it's not a matter of memorizing facts if you have these symptoms. It's not a matter of memorizing what the disease is. He said . . . we have to teach these kids, well not kids, these are med students, adults, but how to find the answers. How to retrieve the answer because there is so much information, and that's science. There is so much that we could never, never know it all. We can only learn the tools and how we are going to access that information. . . . What I am hoping that this scavenger hunt gets across is that there are a lot of ways you can access this information. You don't have to memorize. You don't have to know what the wind speed is of a hurricane if you know how to access it.

Ingle's concern about the implications of the knowledge explosion is, of course, shared by science education reformers. Reformers' principal response has been to focus the science curriculum on an economical set of interconnected fundamental ideas and unifying themes. While some may see the cultivation of information retrieval skills as a useful complement to selectivity, most would argue that it would be best to teach such skills in the context of authentic scientific investigation or problems solving, activities in

which facts are important largely as they relate to ideas with the "rich explanatory power" mentioned in or discussion of Barry's practice.

In contrast to the scavenger hunt for weather facts, a sample of practice that seems more distant from the reform ideal than her lesson on static electricity, Ingle described other lessons that seemed strikingly close to that ideal. In one set of lessons about weather, for example, she recalled posing to students the general problem of accounting for a planet's weather. Students reasoned that a first major variable would be the planet's proximity to the sun, but in examining a chart of temperatures of the planets, they noticed that Venus seemed to be surprisingly hot. Based on further reading, they conjectured that a planet's atmosphere could be a second important variable, and in response to Ingle's questioning, designed and carried out an experiment that involved measuring the temperature of two test tubes located at identical distances from a heat source, one filled with air and the other, with carbon dioxide. Ingle's description was quite detailed and impressive its experimental logic, but we were unable to observe the session and hesitate to cite it as anything other than evidence that Ingle understands how students might be involved not simply in conducting experiments designed by the teacher or others, but in formulating as well as carrying out and interpreting their own experiments.

Ms. Sundmeir: Direct Instruction and Direct Empiricism

In keeping with her commitment to Madeline Hunter's model of teaching, Ms. Sundmeir provided students not simply with a scientific idea they might use to interpret an "experiment," but also with the results and interpretation of the experiment before they completed it. In one lesson, she asked her fourth graders to conduct an experiment on how plants adapt to their environment, or, more specifically, the successful adaptation of desert cacti. Students were placed in groups of 2 or 3, provided small sponges, a bowl of water, paper towels, and Vaseline. They placed the sponges in water for 10 seconds, covered the top and sides of one with Vaseline and placed them both on a wet paper towel. The uncovered side of the Vaseline-coated sponge rested on the paper towel. Once students had completed the first part of this task, Ms. Sundmeir drew an analogy to plants and asked students which sponge was going to stay wet.

> Now let's pretend that these two sponges are plants and there has been a gully washer and there's been a lot of rain. Well, now we will have a drought, a long time between watering. Which one of the sponges do you predict is going to stay more wet?

Thus, she asked students to make a prediction before they conducted the experiment, but in her introductory remarks she had already told students what they were going to "prove":

> Cactus are especially suited to their area; they are specially adapted. Some plants in our area lose 340 cups of water a day [holding up a cup to the class.] Can you imagine how much a desert plant would lose? Most desert plants are covered in wax. We are going to try to prove that if you are covered in wax you won't lose as much water. I am going to have you take a couple of these small sponges. Take your finger and cover one of them -- cover everything on it except the top with Vaseline. The other one leave alone. After this, we are going to put both in water.

Ms. Sundmeir's introductory comments were not an aberration or a slip, but rather an illustration of her conception of how students learn. In opposition to a constructivist approach, Ms. Sundmeir thought it essential that students know beforehand the conclusions of the experiment. This foreknowledge, coupled with hands-on activities in which students somehow assimilate the underlying concepts, promoted, in her view, students' assimilation of scientific knowledge.

> The modeling is really important for them... They don't have a clue... I am a great proficient person in Madeline Hunter. We tell them this is what we are going to do today. This is what I expect you to learn. And I am going to check to make sure you know what you are doing. So they know what they are going to do, where we are going and how we are going to end up. ...With hands-on experiments, they are going to remember it better. The things that I want to get across to them are going to go right up their arms and hands right up to their brains and they will remember forever I hope.

Sundmeir's commentary illustrates two important phenomena. First, teachers frequently interpret practices associated with reform-oriented teaching in terms of ideas from earlier waves of reform. Madeline Hunter's Instructional Theory Into Practice (ITIP) model of instruction, based in the process-product research of the 1970s and early 80s, was extremely influential in Michigan throughout the 80s and seems to remain pervasive, especially at the elementary school level. But in Ms. Sundmeir's practice Hunter's explicit instructional approach exists alongside a striking faith in "hands-on experiments" as somehow immediately educative, as though experience produces knowledge directly ("right up their arms and hands right up to their brains"), without an intervening transformation through the process of reasoning from evidence. Deborah Smith found this kind of naive empiricism quite common among a sample of experienced teachers in Delaware (Smith, 1991) and reports that it is also widespread among her intending teachers at Michigan State (pers. commun., 1997). Ball (1992) has found that many teachers hold similar views concerning the use of manipulative materials in teaching mathematics.

As with most other teachers at the elementary level, there was also some question whether Ms. Sundmeir herself fully understood the scientific ideas she wanted students

to learn. She seemed to approve one student's suggestion that each individual cactus adapts to its environment.

> T: What are we trying to prove? Let's listen to a couple of people?
> S3: We are trying to look how the cactus comes back.
> S4: We are trying to figure out whether a cactus really does adapt to its region, and if it is given water, whether it will get larger.
> T: Very good.

During the lesson, Ms. Sundmeir did not distinguish between an individual organism's adaptation within the potential of its own genome and a heritable change in genetic material that leads to long-term adaptation of a species to the environment. The purpose of the experiment, "how plants adapt to their environment," suggested that Ms. Sundmeir was interested in heritable changes, but she seemed to permit students to focus on each individual plant's adaptation (or adaptedness) without reference to genetic alteration.

Thus, while Sundmeir did focus instruction on a "fundamental idea" (adaptation), did solicit predictions about an activity related to that idea, and did guide her students' engagement with the activity, she prepared them for the activity by presenting both the idea and the results of the "experiment." Her processing of the activity was also limited to explanation on her part and fact-oriented questioning rather than questions designed to provoke thought and the kind of student-student interaction that would characterize a classroom science community. Sundmeir's belief that students' experience in carrying out the activity is directly educative might explain the rather minimal processing.

Ms. Bedford: Prediction as Guessing

Like Ms. Sundmeir, Ms. Bedford asked her students to make predictions about what might occur in the experiments they were about to perform as a class. Bedford reported that scientific experiments played a key role in her science lessons and stressed that prediction was an important part of conducting experiments. She said that in her lessons, there is "Always some kind of experiment, or . .something that they're gonna have to go make a prediction about. Then, come back and talk about it--what did they see. You know. . .and . . .put some conclusions to it."

Ms. Bedford said she learned to emphasize prediction from a student teacher she worked with:

> Where she [the student teacher] really got me where I knew, let's just predict. You know, make predictions with the lessons. Let them do some thinking about what they think will happen. She got real good about sharing that with me and that really helped me. So I kind of got that from her.

According to Ms. Bedford, prediction is linked to inference and to the process of exploration in science:

> When they are predicting that is their own prediction. An inference that they are making about what they think or what they see. . . . And we use it in math a lot in estimating. . . . I would say sure, and that [it] is just guessing. If I tell my kids there are good guesses of what you think it is, and you might be correct and you may not be, you know. And the way to find out is to study it and to find out. . . . A good guess is a good guess of what you think it is.

Bedford's comments suggest that experiments were an occasion for thinking and talking about scientific ideas in light of evidence. Prediction (guessing) and inference could loop back on each other as students use experiments to clarify what they thought and learn something new. However, there was a gap between Ms. Bedford's talk and her practice.

In one lesson, Ms. Bedford led her class through an experiment with garbage and decomposition of waste. She explained to the class:

> We're going to take some dirt (soil) and each table is going to be getting five cups. And I 'm going to tell you what you're going to be burying in the dirt . . . People take the garbage and they bury it, don't they? We're want to see what happens to the dirt, the earth when you take it and you put garbage in it? What happens to the stuff? Today you're going to be burying a piece of paper, you're going to bury a piece of plastic, you're going to bury some metal -- a piece of aluminum -- and you're going to bury some food -- a piece of banana peel and a piece of lettuce.

Before passing out the soil and the paper cups, Ms. Bedford read students' names from randomly selected popsicle sticks and asked them to say what they thought would happen to the buried garbage.

> T: All right Amy, what's a prediction?
> S: [inaudible]
> T: When you guess, when you take a guess at what you think of something is.
> T: Matt, tell something you think is going to happen?
> Matt: It's gonna stink
> T: It's going to smell. Brian, what do you think is going to happen to the trash when we bury it.
> Brian: I believe it's going to start, the foods going to start rotting and the room is going to get stinky like . . .
> T: The food's going to rot and get stinky or smelly. Angie, what do you think is going to happen when we bury the trash?
> Angie: It's gonna be gone.

T: You think its going to go away, its going to be gone. Mandy what do you think will happen?
Mandy: It's gonna be e-vap-or-ating.
T: It's going to evaporate. Okay, that's a good idea.

Making a prediction seemed to mean simply taking a guess. Bedford did not press Angie on why she thought the garbage "would be gone," or what she meant by "gone," nor did she follow up with Mandy about why "evaporation" was "a good idea." She did not ask students to explain or justify their answers, or to use scientific ideas and knowledge in formulating and explaining predictions. Nor did she urge students to consider the merits of their peers' predictions and explain why they agree or disagree with each other.

After eliciting students' predictions, Ms. Bedford explained the experiment in a procedural fashion: Each table would have five cups. They were to fill the five cups up halfway with dirt, place one piece of garbage in each, and then top the cup off with soil. She demonstrated for students what they were to do. Ms. Bedford went on to tell students they were going to put the cups up on the window sill, put a little water in each cup ("because the soil would be wet") and cover each cup with cling foil. She made no effort to engage students in thinking about how they might construct an experiment that would allow them to explore how different types of garbage decompose, whether the banana peel would "stink" or whether the plastic "would be gone." There was no explanation of why garbage would be buried, how wetting the soil might affect decomposition, or why covering the cups with foil was significant. Instead, Ms. Bedford outlined and demonstrated what students were to do, and students mimicked what she had done.

Ms. Isaro: Science as Procedure

Ms. Isaro, a fourth-grade teacher, organized students into teams of four to test various designs of a miniature sailboat, or skimmer, that students were building to race in a schoolwide competition. In one experiment, "design teams" were provided with a range of materials -- skimmers, rulers, tape, air blasters, and pennies -- and asked to test whether the skimmer goes farther when carrying extra mass (in this case, a penny or two pennies). Ms. Isaro claimed that the sequence of activities was designed to elicit students' questions or predictions, involve them in sustained experimentation, and enable them to discuss their ideas about the findings. But as the lesson unfolded, the focus was on students properly carrying out each step of the experiment without any opportunity for students to them about the underlying ideas. Ms. Isaro began by asking students to make a prediction.

> Do you think by adding mass, it will make it more stable, will make the skimmer go farther? I want you to predict right now. In today's experiment we are adding mass. What's a synonym for mass? [Student: weight]

Ms. Isaro then asked students who believed that the "weight will help your skimmer to go farther" to raise their hands. After a quick hand check, Ms. Isaro spent 10 minutes explaining to students their roles in the design team:

> Remember the facilities engineer won't be able to carry everything down to the gym but they can carry some things and put people in charge to get others. The test engineer will be the recorder. Once in groups, the recorder is the only one who needs pencil and calculator. What will we use the calculator for?

Ms. Isaro also reviewed the different tests that she expected students to do for the experiment.

> T: How many different trials will you have?
> S: 2, 4
> T: No -- no extra mass, one penny taped, one penny free, two pennies taped, two pennies free.
> S: 5
> T: How many altogether if 3 per trial run?
> S: 15
> T: Once you get into your design team, the development engineer will make sure everybody has a job. Rob, get the turkey basters. The recorder is going to record and can do the calculating. Keep the balloon away from the wall.

Ms. Isaro focused on students' having the right equipment and carrying out the right procedures for the experiment, not on students' grappling with the scientific ideas that they were supposed to be testing. Students spent the largest proportion of time following the handout that described each step of the experiment and recording the results. In the final phase of the lesson, the experimental results were summed up without students having an opportunity to reflect on the concepts Ms. Isaro had suggested were the focus of the lesson's activities. Ms. Isaro asked students, "How many of you had the farthest distance in no extra mass?" After all groups raised their hands, Ms. Isaro stated: "Do I need to go further? Why? Every single group was in there. Did your prediction come true?" After one student said yes, Ms. Isaro closed discussion and told students that the next experiment would be on the design of the sail.

Ms. Isaro's procedure-oriented approach represented a rather narrow conception of what a community of scientists do. Interestingly, the curriculum she used had been designed by Ford Motor Company engineers to model the collaborative activity of

scientists in the workplace. But the roles students assumed were confined to carrying out a function that required following procedures without reasoned discussion and debate about conclusions. There was no real give and take among students about what design would best produce the fastest skimmer. Consequently, the community Ms. Isaro had established in her classroom most resembled the kind of teamwork currently emphasized in many contemporary occupations where people work together to carry out narrowly specialized tasks without autonomy outside of prescribed directions and with the expectation of standardized results.

Ms. Land: Students as Volunteer Constructivists

Ms. Land, a fourth-grade teacher, began a lesson aimed to help students learn "that plants have definite parts and that food comes from plants." She placed students in groups of four with each group receiving a different kind of plant. Each plant was about a foot high and had exposed soil-laden roots. After students spent a few minutes "observing the plants," Ms. Land asked students to identify their parts. Students said that they observed roots, leaves, stems. One or two students said 'soil.' Ms. Land at first overlooked or disregarded the comment and went from group to group, asking students whether they had identified, respectively, the leaves, stem, and roots for their plant. After each group responded affirmatively, a student returned to the question of whether the soil is part of the plant:

S1: Plants can't live without it, but soil isn't part of the plant.
S2: If you soak the soil in water it all comes off and is therefore not part of the plant.
S3: The plant eats the soil.

Ms. Land permitted students to offer ideas but her response to students was, "The soil becomes part of the plant." Rather than settling the matter, this set off another round of student comments:

S1: The soil is holding the plant together.
S2: The plant absorbs it or something.
S3: Like she said, it absorbs it. Part of me says it is part and the other part of me says it's not a part.
S4: If you shake the plant, the soil comes off, but not the leaves; if you break open a bean, you don't find soil.

Once again, Ms. Land did not initially stifle students' comments, but she was unable to connect them to any larger conceptual framework related to plants. For example, Ms. Land's overall comment after listening to students discuss whether soil was part of a plant was:

> It seems based on students' raising their hands that students believe soil has something to do with plants. Boys and girls, soil has definitely something to do with plants, but it is not a part.

To her credit, Ms. Land encouraged students' comments and questions. At one point, she even wrote on the board, "Is soil a plant part?" presumably to return to it later. However, Ms. Land herself stated that her grasp of the scientific ideas was weak, saying at one point, "I'm struggling with this myself." Once Ms. Land reached the limits of her own grasp of the content, she provided students with an answer and moved them through another activity.

One is reminded of the joke by Rodney Dangerfield -- a noted authority on the importance of mutual respect in discussions -- about going to a prize fight where a hockey game broke out. In the middle of a lesson focused primarily on identification of the parts of a plant, a scientific community threatened to break out. Students began to puzzle with each other about the question. They made nice distinctions : "Plants can't live without it, but soil isn't part of the plant." They reasoned from evidence: "If you soak the soil in water it all comes off and is therefore not part of the plant. They listened to each other, "Like she said, it absorbs it." They expressed ambivalence rather than adopting fixed positions prematurely "Part of me. . . part of me." They gave multiple reasons: "If you shake the plant, the soil comes off, but not the leaves; if you break open a bean, you don't find soil." These students engaged with the activity not to produce dramatic effects or to make it "work" as designed, but as people who were genuinely interested in making sense of what they were seeing. They exceeded the design. Gardeners refer to plants that spring up without being deliberately planted or cultivated as "volunteers." These students were volunteer constructivists.

Initially, Land encouraged her volunteers. Perhaps they knew from prior experience that such speculation would not be quashed summarily. The question of whether soil is part of the plant is closely related to the idea that "food comes from plants," which Land seemed to regard as a simple descriptive matter about where some of the things we eat come from rather than an absolutely fundamental scientific idea about how life is sustained. Had she understood the content more fully, one senses, she might have been able to use the "natural curiosity" beloved of constructivists to help students make some progress toward an understanding of photosynthesis. Instead, she seemed to feel obligated to clear up students' confusion and move along to another activity.

Ms. Townsend: Dramatization, "Oops," and Reflection on a Failed Experiment

In the classrooms we observed, experiments were seldom formulated by the teacher and students to test an hypothesis they had developed. Instead, nearly all were pre-fabricated. With materials assembled and procedures fixed in advance, teachers offered students an opportunity to witness a demonstration rather than pose new questions that

an experiment could answer. Yet, even a prefabricated experiment can offer powerful lessons about how scientists "do science": how they construct knowledge under controlled circumstances, test hypotheses, and record data. Experiments can also dramatize scientific ideas with real immediacy.

As we have seen in the case of Ms. Ingle's static electricity lab, however, prefabricated experiments do not always unfold exactly as planned. As Ms. Townsend explained,

> We do a lot of hands on in science. . . . We do a lot of experimenting and recording, and discussing . . . . It's either some type of experiment or looking at something, and . . . I think they learn better that way. . . . It makes more sense to them. They understand it more. And I think it gets them to ask more questions. . . actually doing something rather than listening about it or reading about it. I think they get more out of it. They actually see it, versus not, you know because then we can say, wow I didn't realize this did that, or why this did what it, it did, or oops. This is why we do things with concrete objects.

An example of Ms. Townsend's "oops" occurred as she was using a unit on plants developed by the Michigan Department of Education. The experiment was intended to show that plants give off oxygen and take in carbon dioxide. In one large pickle jar Townsend placed a dinner table candle; in another, a candle and a potted plant. The premise was that when the two candles were lighted and the jars sealed, the candle in the jar with the potted plant would burn longer because the plant would give off oxygen beyond what was initially sealed in the jar. Giving stop watches to two students who were designated as time keepers, Ms. Townsend and her resource teacher lit the candles. Each taking responsibility for one of the jars, they then put on the lids simultaneously and shouted "go" to the time keepers. The students immediately pressed the stop watches. All eyes were glued to the two pickle jars for the next two or three minutes. As they watched, Townsend initiated some sporadic conversations by asking some questions but did not sustain them. The candle in the jar with the plant burned out 61 seconds before the other one. Townsend said, "It didn't work, because this one's the one that is supposed to last longer."

Like Ms. Land's volunteer constructivists, Townsend's students spontaneously began to offer reasons as to why the experiment might not have worked. A number of students suggested changing candles because (as some students noted) one candle might be bigger than the other. Another student suggested that the teacher and resource teacher should each take a different jar next time. Townsend decided to consider students' speculations:

T:	Let's stop and think why maybe it did that. Now Heather had an idea?
Heather:	Because maybe when you closed it more air got locked in.

T:	In that one [pointing to the jar without the plant]"
Heather:	Yeah.
T:	Now David had an idea too?
David:	Plant taking up more room, it takes up room for the air.
Resource T:	Put a smaller plant in?
T:	A smaller plant or a smaller candle?
David:	I think you need a smaller [pause] candle in [uncertain].
T:	Leave this plant and put a smaller candle in [some students nod in agreement] we'd have to put a smaller candle in both of them . Should we try that?
Ss:	Yeah.

At this point Ms. Townsend and the resource teacher did the experiment again using birthday candles. Again all students watched intently. This time around the experiment "worked." There was no further discussion, however, as to why the experiment turned out in two very different ways.

Thus, students initiated the analysis by offering possible explanations for the experiment's "failure" without any prompting from Townsend. Townsend then decided to take a closer look at some of the reasons students offered. But she did not follow students' speculations in any great depth. She let Heather's suggestion die even though it seemed as plausible as David's. Moreover, the manner in which she re-designed the experiment in response to David's suggestion did not directly address the issue that David raised -- that the plant was taking up a sizable amount of the available space in one of the jars and may have reduced the jar's capacity to hold oxygen relative to the other jar. So although Ms. Townsend did entertain students' suggestions towards the end of this lesson segment, she never managed to take them in a direction that would have encouraged students to grapple with substantive ideas about oxygen and carbon dioxide and/or the process of carrying out scientific experiments. As a result, the notion that plants give off oxygen was reduced to little more than something for students to remember; and the "experiment," to a somewhat mysterious dramatization.

There was nothing to suggest to students that experimentation was a way of coming to know scientific knowledge. At best, experiments were a way of validating or perhaps of "showing" existing information. The failure could have been used to help students come to appreciate the scientific process in a more authentic way. Ms. Townsend might, for example, have asked students what they thought this suggested. "Do plants really give off oxygen?" "How might we find this out?" "If plants give off oxygen, and given what we know about oxygen and fire, then what might account for the outcome of our experiment?" Questions such as these, carefully played out, might have fundamentally transformed the scientific experiment, enabling students to engage in constructing or at a minimum, reconstructing knowledge about scientific inquiry. The two "trials" might have revealed something important about careful methodology: creating exact duplicate

conditions is central to a comparative investigation. As the reform documents suggest, to learn science is to learn how to construct knowledge in a scientific manner -- one that may necessitate precision, carefully tested predictions, revised predictions, and careful reflection on the data that emerge. Exploited properly, "failed experiments" could provide material for reflection on "the scientific method" and the phenomenon under investigation through analysis of what "went wrong" and why.

Ms. Bach: Science as Literacy, Community as Harmony

An energetic, inventive woman in her forties, Ms. Bach had been teaching for only five years, all five at a small elementary school located in a rural area along the edge of a small city district. Having obtained her bachelor's degree just before coming to Sylvan Elementary, she had immediately gone on to complete a master's in teaching at the same nearby regional university. Though her science methods coursework had acquainted her with reform-oriented ideas about children's misconceptions and clinical interviewing as a technique for learning about them -- an informal version of which she used with some regularity -- her teaching seemed to owe more from current ideas from reading or "literacy" instruction than to the science reforms.

A lesson on earthworms, for example, focused largely on facts and terms rather than on ideas with broad explanatory power, but Bach used a "KWL" framework to weave many of the facts into the fabric of students' prior experience so that the facts took the form not of bare lists, but of an interpreted factual network. That is, the KWL approach (what do I Know already, what do I Want to know, and what did I Learn?) seemed designed to motivate and contextualize the collection of facts, framing inquiry of a certain sort, but the investigation led largely to an interlinked set of facts and experiences rather than to a conceptual account of a phenomenon or system. It occasionally called forth rudimentary explanations, but could not be said to have developed or called upon powerfully explanatory ideas.

A bulletin board already in place before the lesson began afforded a glimpse into some prior lessons in the unit. One, on the windowed side toward the back of the room, was entitled, "We Are Digging into Dirt," with the subtitle, "Soil and Earthworms Unit." It was divided into three columns: "What do I know?" What do I want to know?" "What did I learn?" Some items under "What do I know?" were these:

1. You can cut an earthworm in half and it still lives.
2. Earthworms dig deep into the soil when it is cold.
3. Earthworms loosen up the soil.

.

.

10. Earthworms have three hearts.
11. Earthworms are chubby even after they have young.

Some items under "What do I want to know?":

1. What kind of soil do earthworms like best?
2. How do they have babies?
3. What exactly do they eat?

.

.

.

9. Do they "go to the bathroom"?

.

.

12. How long do they grow? (length)
13. What age can they give birth?
14. Do they have live births or eggs?

The "What did I learn?" column was still blank. Below the KWL columns were several labeled drawings of earthworms, executed on computers.

Ms. Bach set up the first segment of the lesson by telling the students that before she could distribute the earthworms for observation, they needed to know more. (She later said that she had already read a short booklet on worms during the morning.) She reviewed some of the things they had already "talked about," including "some things we know about worms," "what they eat," "some things that we still don't know about them," "body parts so when you get your worm you'll be able to identify some of those body parts," and so on. As they listened to another book called, "How Earthworms Live," students were to write down the new things they heard, not things they already knew. Each was to write down at least two things. She explained that " ... all of this new information that you have is gonna help you do a better job when you observe your earthworm. You will know some new words to use. You won't just say, 'that brown part.' "

Bach read the entire booklet quite deliberately, checking between sentences to see whether students were following her. Occasionally she would stop to hold up a picture, moving around the class to assure that all students had an opportunity to see it. The students generally seemed attentive. They gasped when it was revealed that some earthworms grew as long as nine feet. Some wrote busily throughout the reading, but on the whole, the writing diminished sharply after most students had recorded the obligatory two items. The book was in clear, declarative language and very fact-packed (more than 100 segments, round and long muscles, movement aided by use of bristles, some under an inch, etc.).

The following exchange illustrates the level of explanation to which the interleaved discussion of the reading sometimes rose:

> B. stopped to ask why people could not move like a worm.
>
> "We're not as flexible," a girl answered.
>
> "Why are we not as flexible? That is a right answer, but why are we not?"
>
> "We have bones," a student pointed out.
>
> "Have bones, okay, so we 're getting close. So it has something to do with those bones. David, whaddya think?"
>
> David started to say something, then apparently forgot why he'd had his hand in the air."
>
> "Oops, forgot." B. said, then called on another student.
>
> "We don't have bristles."
>
> "Don't have bristles...." said B. thoughtfully but noncommittally. "Think about what X said and think about what Y added, and I'll tell you they're on the right track. Z, whaddya think?"
>
> "Backbone."
>
> "Oh, wonderful that's exactly right." Bach went on to explain that people and many other animals, such as birds and horses, have backbones. She appeared to resume reading, "An earthworm has no bones at all...."

As Bach continued to read, she paused from time to time for similar questions. She was constantly using the KWL framework, activating prior knowledge or misknowledge in relation to new information from the text she was reading. She defined any new term, referring to things in the students' experience. The questions frequently prompted students to make explicit things that one might easily pass over as assumed (e.g., worms like compost heaps because of the decaying leaves, but what do they like about leaves -- they like to eat them). Some questions called on students to recall terms they had learned earlier in the unit ("organic matter"). She often elaborated on the text (e.g., after reading that each worm digs his own burrow, she noted that this means that "There isn't any contractor worm. Nobody comes in and builds them a house.") All in all, the reading represented a rather nice example of shared interpretation of a text.

Despite all of the questioning and textual interpretation that Bach worked into the reading session itself, when she completed it, her questions reverted to the purely factual. Every student was given an opportunity to read out a fact s/he had written down, even when they simply repeated what others had recorded. There was no effort to distill any organizing ideas or even any overall impressions of what they had learned. The tacit message of the discussion phase seemed to be that science is about facts -- maybe interesting facts, or facts about things that the students were interested in, but facts.

Mapping the KWL approach used by Bach, a staple of current reforms in literacy instruction, onto the teaching cycle presented earlier, which schematizes some notions from current reforms in science education, is instructive. The "K" phase, mobilizing prior knowledge, maps roughly onto preparation. In Driver's (1995) account, preparation also involves mobilizing prior knowledge, often if not always by asking students to make a prediction about some phenomenon and following this up with questions designed to get them to spell out the way the way they are conceptualizing the dynamics of the phenomenon. Bach's preparation also calls forth some misconceptions (e.g., worms have 3 hearts), but these are "misconceptions" more in the everyday language sense of mistaken factual statements than in the scientific sense of conceptual misunderstandings about the dynamics that underlie observable phenomena. Bach's "W" phase (what do you want to know) amounts to the stimulation and validation of curiosity as part of the preparation. In Driver's model, curiosity may also play a role -- curiosity about whether one's prediction will prove out -- but dissonance between the prediction and what is observed while carrying out a scientific activity (experiment) is the chief motivator as well as providing the substance for examination during the processing phase. Surprise about mistaken assumptions may figure in Bach's teaching, as well, but her primarily factual focus makes it unlikely that major conceptual reorganization will occur. Bach's questions about what students learned, at least during the session cited above, were also largely factual and did not prompt the sort of processing (reasoned argument toward conceptual understanding) that science education reformers envision. Literacy researchers (e.g., Rosaen, pers. commun., 1997) point out that the KWL framework can and often should be used more conceptually, but we suspect that Ms. Bach's practice is not atypical in its primarily factual focus.

As indicated by Bach's remark that "all this new information. . . is gonna help you do a better job when you observe your earthworm," hands-on activities had a prominent place in her teaching repertoire. A subsequent lesson on soil involved students in close examination of soil samples, weighing them, and making notes of their observations. In the follow-up discussion, however, as in the lesson on earthworms, Bach accepted virtually all responses to her questions, occasionally paraphrasing them to insert a term she wanted them to learn, but never comparing them or inviting students to take issue with what others reported, even when the discrepancies among observations were

striking. Asked about the fact that students did not take issue with each other, Ms. Bach said:

> Bach: This group is to the point where they are pretty accepting to different sets of opinions on stuff and . . . they know that they all bring a different perspective to something. We talked a lot about that so they are well aware of that. . . . they are more accepting of that than they were at the beginning of the year. . . And in that sense I know that they are more accepting of each other. And that is only because I observed them over time that I can tell you that.
>
> Int.: So their being more accepting of each other is, from your point of view, more important than whether they converge on. . .
>
> Bach: No, I don't think that is more important, but I think it is an important concept that they are picking up. That other people's opinions matter. That is really important.

Thus, while Ms. Bach had obviously worked hard to create a harmonious community characterized by mutual respect among students within her classroom, such a community of acceptance is quite different from a scientific community governed by norms of reasoned discourse seeking to establish the truth of claims through argument based in logic and evidence. Though other teachers did not make the same explicit case for a dominant norm of mutual acceptance that Bach made, we got the strong sense that she is not alone in seeming to value social harmony over scientific argument in the classroom.

Patterns of Practice

As we saw in our discussion of Ms. Barry's practice, contemporary reform documents call on teachers to focus the science curriculum on an economical set of fundamental ideas, ideas connected with each other in theories, models, and broader networks of mutual implication as well as with "real world" natural phenomena and designed systems. Teachers are to guide students in constructing and using these ideas as they observe, describe, and explain the dynamics of phenomena encountered through first-hand experience. Students' encounters with and efforts to make sense of the phenomena should be mediated by a supportive physical environment and a social environment governed by norms of investigation and discourse like those that govern larger communities of professional scientists. Assessment should be continuous, providing a view of students' evolving understanding that can be used to shape instruction.

As we have also seen in the foregoing snapshots of other teachers' practice, current practice -- even among teachers whose reports of their own practice include many

features consistent with the reforms -- is often quite distant from the reform ideals. In this section we offer an overall characterization of the patterns of practice we observed. Doing so requires considerable simplification, but without dropping out texture, detail, and qualification, it is impossible to see or show the broader pattern.

Speaking quite broadly, then, our teachers tended to emphasize four different types of content: facts, procedures, impressions, and ideas. Though reformers often seem to regard the distinction between facts and ideas as self-evident, it is actually subtle and complex -- too subtle and complex to permit a full exploration here. For present purposes, an illustrative example will have to suffice. By "facts," we refer to the content of statements such as this: the earth revolves around the sun in a nearly circular but slightly elliptical orbit and as it completes the circuit, makes a complete rotation on its tilted axis about 365 times. By "ideas" we refer to the content of a complex of propositions such as this: it is hotter in the summer than in the winter not because the earth is closer to the sun, but because the tilt of its axis during the summer segment of its orbit makes the sun's rays strike a spot in one hemisphere of it (1) more directly, thus concentrating the relatively constant light energy from the sun rather than dispersing it as happens when the tilt is oriented differently in other segments of the orbit, and (2) for a longer period during each rotation.

Thus, while the terms "revolution," "orbit," "rotation," and "axis" may designate concepts, when they are taken independently, in lists, or in straightforward descriptive statements, most science reformers would classify them with facts rather than ideas. Even patterns discerned in observations -- for example, that the earth rotates on its axis about 365 times on each revolution around the sun -- do not qualify as "ideas" in the lexicon of the reforms. Rather, some level of explanatory power -- propositions that link concepts together to explain observed patterns -- characterizes reformers' "ideas" and differentiates them from "facts."

By "procedures," we mean systematic steps or techniques that students carry out under teachers' direction, such as taking measurements and recording observations. "Impressions" is the term we coined to designate the mental residue of "hands-on" activities carried out by students but left virtually unprocessed, not discussed or written about or reflected upon in a way that would help students to distill conceptual meaning from the experience, or even to clearly identify facts to remember from it. Instead, in these cases, students seem to be left with some melange of visual images and other sensations that they might be able to assemble into narrative accounts of what they did and what happened, but little more.

Science as Facts

As Table 2 indicates, the message conveyed by eleven of the twenty two teachers we observed was that science is primarily about facts, not fundamental ideas[1]. In no case, however, were these facts simply presented in lectures or listed on worksheets. They were sometimes linked to prior knowledge and with each other, as in Ms. Bach's KWL lesson on earthworms; and sometimes made concrete through direct observation, as in Bach's lesson on soil or Ms. Land's lesson on plant parts. At other times they were lent vividness and excitement through the use of lively texts or art work. Ms. Lark, for example, read from The Magic Bus, an imaginative book designed to help students understand the food chain in the ocean and asked questions calling for factual recall (anchovies ate the plankton, were then eaten by the tuna, and so on). Ms. Newberry's classroom was rich in colorful art work and illustrations (e.g., oversized masks of various bat species), but students' oral reports about bats remained factual. Thus, half of the teachers in our sample treated science as largely a matter of facts, albeit contextualized, exemplified, or vivified through the use of methods adapted from other subjects, hands-on activities, lively narrative or expository texts, and art work. All but one of the teachers who treated science as facts were elementary teachers, none of whom mentioned special preparation in science. Ms. Winston, the lone middle school teacher in the group, had majored in home economics with a child care science endorsement .

A somewhat more detailed examination of these teachers' pedagogy in terms of the cycle discussed earlier reveals, first, that preparation for activities often did include substantive as well as procedural components such as questions designed to prompt recall of prior knowledge (generally from earlier lessons) or the presentation of new information intended to be used during the activity phase. But whether mobilizing prior knowledge through questioning or introducing new information, substantive preparation remained factual rather than idea-oriented.

When they asked students to make predictions concerning the outcome of experiments, these teachers did not follow through by asking students to explain why their predictions might be plausible or what mechanisms might produce the outcomes they expected. Instead, the predictions were treated simply as guesses. In fact, "prediction" was often defined quite explicitly as " a guess." The significance of this is that students were not prepared to see the results of the "experiments" or other activities as sources of evidence concerning some hypothesized explanation. Making predictions seemed in

[1] For simplicity of presentation, Table 2 includes a summary of only one of the two lessons observed for each teacher, but in no case was the lesson not summarized more reform-oriented than the lesson included in the Table. In most cases, the two lessons were about equally reform oriented in both content and pedagogy. But in a few cases -- such as that of Ms. Ingle -- the two lessons did differ materially. In these cases, we chose to summarize the more reform-oriented lesson. Thus, the chart may overestimate the degree to which current practice realizes the reform ideal, but it is unlikely that it overestimates the reforms' progress.

Table 2

SCIENCE CONTENT AND PEDAGOGY

					PEDAGOGY		
CONTENT	TEACHER	DISTRICT CONTEXT	LEVEL	LESSON EXAMPLE	PREPARATION	ACTIVITY	PROCESSING
SCIENCE AS FACTS	Judy Bach	Rural	Elementary	Earthworm facts	Teacher poses questions to recall earthworm facts from prior lessons; Gives instruction to students to recall two new facts	Teacher reads expository text peppered with interesting facts; Students observe and measure live earthworms	Teacher solicits and accepts students' reported observations with little student-student discussion
	Karen Bedford	Urban	Elementary	Decomposition of waste	Teacher reviews definition of decomposition; Students predict without explanation what will happen to buried garbage; Teacher specifies procedures for activity	Teacher reads expository text on waste disposal; students bury pieces of garbage in soil	None in this lesson. Teachers plans later discussion of findings
	Nan Dingle	Rural	Elementary	Simple machines make work easier	Teachers asks students to read text on simple machines & reviews with students author's main points; Teacher asks for examples of incline planes	Students in groups test whether a pointed-tip nail or a blunt-tip nail best reduces work	Teacher asks students to report observations; Some students claim no difference between nails. Teacher gives students the reason for experiment's failure
	Lynn Iben	Suburban	Elementary	Sources of light; definitions of translucent, transparent, opaque	Teacher solicits students' prior knowledge about light and asks for definitions. Students predict without explanation what happens when light passes through a marble	Students in groups test what happens when a small flashlight shines on a marble	None in this lesson. Teachers plans later discussion of findings.
	Darla Land	Rural	Elementary	Parts of plants	Students predict without explanation how much plants in the class have grown in one week.	Activity unrelated to predictions; Students in groups observe and identify parts of plants	Teacher led fact-oriented discussion about plant parts; Students volunteer questions & comments
	Isabel Lark	Urban	Elementary	Food chain examples	Teacher reviews example of food chain on land by drawing illustrative diagram on poster	Teacher reads imaginary story that illustrates an actual food chain that exists in the ocean	Teacher write on board diagram illustrating food chain in ocean; Students copy down diagram
	Kathy Newberry	Urban	Elementary	Facts about bats	Teacher describes personal encounter with bat; Teacher places bat silhouette on overhead; Students compare bat & human anatomy	Teacher reads expository text about bats and their anatomy	Teacher & students discuss facts about bats in text; Students begin work on creating a bat replica using cardboard and toothpicks
	Corinne Quant	Urban	Elementary	Objects magnets attract/don't attract	Teacher asks students to make predictions without explanations on which objects the magnet will/will not attract; Procedural preparation	Students in groups test their predictions on objects' magnetic attraction	Teacher and students together summarize findings illustrating number of objects that did/did not attract. One student says objects attracted contained metal. No further discussion.
	Lori Townsend	Rural	Elementary	Plants give off oxygen	Teachers outlines procedural preparations for "experiment" to "prove" plants give off oxygen	Teacher demonstrates "experiment" while students observe	Teacher declares "experiment" a failure; Repeats demonstration without sustained discussion of reason for initial failure
	Pam Winston	Suburban	Middle	Elements on the Periodic Table	Teacher asks students to prepare their individual presentations on one element in the periodic table; Students prepare charts, models, and texts for their presentations	Individual students do presentation, telling name of element, symbol, atomic number,, history of the element's discovery along with some of its contemporary uses and benefits	After each student's presentation, teacher and other students raise fact-oriented questions and ask for clarifying information
	Lisa Wright	Urban	Elementary	Facts about hurricanes & tornados	Teacher asks students to create questions for use in a board game on weather-related facts	Students create questions while watching a movie on hurricanes and tornadoes	Based on movie dialogue, teacher asks students fact-oriented questions

Table 2, p. 2

SCIENCE CONTENT AND PEDAGOGY

					PEDAGOGY		
CONTENT	TEACHER	DISTRICT CONTEXT	LEVEL	LESSON EXAMPLE	PREPARATION	ACTIVITY	PROCESSING
SCIENCE AS PROCEDURES	Joe Glover	Suburban	Middle	Chemical reactivity of metals	Teacher asks student to make predictions without explanations in chorus on what metals are more reactive than copper; Teacher specifies and reviews procedures	Following procedures the teacher has written on the board, students in groups carry out nine tests on metals' chemical reactivity and complete laboratory handout	Teacher admonishes one group for not following proper procedures; Teacher summarizes findings by asking students about the reactivity of the metals; Students clean-up lab
	Nancy Isaro	Suburban	Elementary	Mass and its effects	Teacher asks students to make predictions without explanations on whether a boat will go farther with increased mass; Teacher specifies and reviews procedures	Students in groups test predictions using minature boats that carry increased mass in the form of a penny or pennies	Teacher asks students to report findings without further discussion
SCIENCE AS IMPRESSIONS	Jane Fond	Suburban	Middle	Exothermic chemical reactions	Teacher specifies procedures for making ice cream	Students in groups attempt to make ice cream, compare and taste products	Students express to teacher appreciation for activity; Optional completion of questions on temperature of reaction
	Maria Turner	Urban	Elementary	Buoyancy	Teacher asks students for predictions without explanations on which objects will float or sink; Teacher demonstrates activity	Students in groups test whether different objects; e.g., plastic boats of various shapes and sizes, sink or float	Teacher elicitation of group findings; students suggest cause of boats sinking was flat bottoms; Superficial discussion with no attention to student misconceptions
	Iris Vargas	Urban	Elementary	Craters on the moon and earth	Teacher demonstrates how to make a crater by dropping a rock into sand	Students in groups make a crater by dropping a rock into sand	Teacher judges students' craters to determine realistic appearance
	Susan Young	Urban	Elementary	Buoyancy	Teacher asks students for predictions without explanations on which objects will sink or float	Students in groups test whether different objects; e.g., rubber bands/plastic boats of various sizes and shapes, sink or float	Group report of findings; Students report discrepancy on whether a rubber band floats or sinks; Further testing to resolve discrepancy; rubber band floats briefly sinks slowly; Superficial discussion why
SCIENCE AS IDEAS	Betsy Barry	Rural	Middle	Concept of work & simple machines	Teacher reviews the concept of work by asking students to identify and explain resistance and effort arms on visual model	Students in groups build different models of simple machines and attempt to determine a relationship between the length of the effort arm and amount of force needed to lift a standard load a certain distance	Teacher asks students to volunteer what they learned from activity; Teacher displays different classes of levers and asks students to identfy parts; Students engage in discussion of location of fulcrum, effort arm & resistance arm on different levers
	Karen Ingle	Urban	Middle	Static electricity	Teacher prepares students for laboratory and asks student for the definition of static electricity; Student reads from notebook that it is the build-up of electrons on an object	Students in groups attempt to observe static electricity by rubbing a comb with wool and touching it to two pith balls or rice puffs hanging side by side	During students' experimentation -- some of which failed -- the teacher attempts to elicit students' thinking about what was going on below the surface of the phenomena
	Emma Nelson	Urban	Middle	Necessary components of fire	Teacher poses questions to students about three components (heat, fuel, oxygen) needed to make a fire; Teacher explains why steel wool burns and steel nail does not; Teacher reviews safety procedures	Students in groups go outside and attempt to build a fire using "fire triangle" to guide efforts	Teacher congratulates students on safety habits; Students return materials; Brief review without discussion of why some groups more easily started fires than other groups
	Opal Sundmeir	Suburban	Elementary	Adaptation of desert plants	Teacher tells students that they will try to prove that plants adapt to their environment; Students make predictions without explanations	Students in groups soak two sponges in water and cover one with petroleum jelly on three sides to determine which sponge will retain water and why	None in this lesson. Teacher begins another demonstration experiment to illustrate same idea.
	Judy Turnby	Suburban	Elementary	Testing a river's ecological health	Teacher discusses with students that they will conduct a variety of tests at a local river to help determine river's ecological health	Students in groups conduct tests on tempreature of river and pH level of river water; Students also measure river velocity and width	None in this session. Teachers plans later discussion of tests and their meaning.

many cases to be something that teachers knew that scientists do and that they should ask students to do, but the function of prediction -- other than heightening students' interest by creating suspense regarding who was "right" -- was not so clear. Of course, scientists frequently do undertake explorations without a really clear sense of just what they expect and why -- or even, sometimes, of exactly what they are looking for -- but these fact-oriented teachers did not provide for the kind of post-experiment processing that would be required to capitalize on such open-ended explorations, either. In a few cases, teachers told students in advance what the "experiment" was designed to demonstrate.

As already indicated, the function of the hands-on activities that students carried out was generally to dramatize or enliven fact-oriented lessons -- to make the facts more memorable and the lessons more fun -- rather than to generate data which students might reason about. And as the frequent use of quotation marks around "experiments" indicates, these activities were generally not experiments in the strict sense of the term, but demonstrations of facts known in advance. In several cases, students did use the knowledge teachers had provided them, but the use was almost always descriptive (e.g., the "saddle" of the earthworm rather than "that brown part"). In a few cases, the information was used in a more interpretive or explanatory way (e.g., the facts that earthworms have no bones explains why they are more flexible), but these explanations were too rudimentary and disconnected from larger conceptual frames to qualify as "ideas" in reformers' terms. Students were often grouped into threes or fours for the activities, but tended to work in parallel, consulting each other only about procedural matters, not discussing substantive ideas. Similarly, the teachers' guidance and facilitation was largely procedural, only occasionally and fleetingly interpretive, and not focused on promoting substantive discussion among the small groups.

Turning to the processing phase of these lessons, a principal format was the summarization of facts observed or confirmed through the activity phase. Students sometimes initiated attempts to explain unexpected results (e.g., the candle in the container with the plant going out first) or to clear up confusions (e.g., whether soil is a part of the plant), and while teachers did sometimes entertain these questions with students, they seemed uncertain of how to exploit them through fuller student-student discussions focused on explaining puzzling phenomena. In fact, student-student discussion was notably rare and was seldom initiated or sustained by teachers on the few occasions when it did occur. The message that civilized argument using evidence and logic should be a central activity in science education did not seem to have reached (or at least persuaded) these teachers. Thus, there was little that might be considered reflection on the warrant for scientific explanations.

Science as Procedures

One middle school and one elementary school teacher's lessons conveyed the message that science is primarily about following correct procedures. In these cases, exemplified in the snapshot of Ms. Isaro's lesson above, students were so absorbed in following the steps specified by the teacher (sometimes described as "the scientific method") that ideas were eclipsed or altogether neglected, and even facts seemed of subordinate importance.

In the preparation phase of both sample lessons summarized in Table 2, the teachers asked students to predict the outcomes of the tests or experiments to be undertaken, but as with the fact-oriented teachers described above, they did not ask students to explain their predictions. Each specified with considerable care and precision just what students were to do as they carried out the activities. Students worked in small groups to conduct the activities, but exchanges among them were preoccupied with carrying out the tests or experiment and recording the results properly, not with explanation. The activities did yield data to permit a judgment on the accuracy of predictions, but the judgment was binary (correct or incorrect) and seemed less important than correct execution of the procedures. The small groups' findings were reported or registered in a whole-class follow-up session, but the teachers did not initiate, guide, or facilitate a discussion. In one case, a working group of students were taken to task for not following the specified procedure correctly. There was little sense that these classrooms were scientific communities concerned about the warrant for explanatory claims.

Science as Impressions

The lessons taught by one middle and three elementary school teachers seemed to leave students with impressions rather facts, procedures, or ideas. In these classrooms, students were encouraged to participate in engaging scientific activities and experiments. But in the lessons we observed, the teachers did not move students from their impressions of the phenomena to a consideration of scientific concepts. For example, Ms. Young involved students in an exploration of whether boats of various sizes remained buoyant when different weights were attached. In the preparation phase, students made predictions, and in the processing phase Ms. Young questioned them about their findings. The conversation, however, never reached the level of how size, weight, or density affect buoyancy. The variables that might be in play were never clearly identified, and thus there could be no effort to vary each systematically while holding the others constant. Beyond their impressions of the experiments and the ensuing sketchy conversation, there was never any crystallization of an idea, nor even explicit identification of a scientific fact made more memorable through the experience (nothing beyond which boats floated and which sank).

Another teacher, Ms. Fond, engaged students in an interesting experiment in which students were given a procedure to make ice cream as a way to explore what in an

interview she termed "exothermic chemical reactions." But during the actual lesson, Ms. Fond neither mentioned, asked questions leading towards, or explained the concept of exothermic chemical reactions. Instead, the lesson appeared to focus exclusively on students' involvement in an enjoyable non routine activity. Ms. Fond reported that she had discussed with students both endothermic and exothermic reactions in earlier lessons, but she neither invoked these ideas during the ice cream lesson nor led students to conceptualize such reactions for themselves. It is possible that Ms. Fond and other teachers in this group engaged students during subsequent lessons in making conceptual sense of the experiences, but the observed lessons themselves gave no evidence of this and the interviews were not persuasive on this score.

For each of these teachers, the assumption seemed to be that the experience of conducting the activities would, directly and without any guided, public processing of the experience, teach students something related to science. As noted earlier, Deborah Smith (1991) has found a similar "naive empiricism" among both intending preservice teachers and experienced elementary school teachers of science.

Science as Ideas

Another group of five teachers taught a science of ideas, but just how well-developed, fundamental, and connected the ideas were varied sharply, as did the pedagogy through which the teachers had students engage the ideas. As indicated the foregoing section on Ms. Barry and the New Vision of Science Education, in one lesson Ms. Barry introduced and elaborated the concept of work (work = force x distance) and had students use it as they carried out, collected data on, and explained the results of activities involving levers of three classes. Barry also gave a persuasively detailed account of other lessons in which the concept of work was used in activities involving a range of other simple machines. Schematic representations of the machines were connected with actual machines familiar from daily life. Thus, the idea addressed by Barry was reasonably well-developed or well-defined, relatively broad in application, and connected conceptually and to real-world contexts. Barry's pedagogy did involve students in scientific activities requiring them to use the ideas and to some degree in constructing (clarifying, thinking through) aspects of them for themselves. This construction was somewhat truncated at the "front end" -- the preparation phase -- when Barry presented the concept of work rather than eliciting students' ideas in a way that would have set up the post-activity processing. Her guidance and facilitation of the activities and the post-activity processing provided focus and structure, consisted more of questions than of answers, and orchestrated student-student discourse for purposes of making sense of data from the activities. Particularly in the crime scene lesson, Barry made reflection on the warrant for claims quite central, and throughout, her classroom conveyed a real sense that students composed a community of inquirers in which authority was vested at least as much in evidence and argument as in the teacher. All in all, Barry's practice

represented a reasonable approximation to, though not a perfect realization of, the reform ideal.

Like the content of Barry's lesson on levers, the main idea in Ingle's static electricity lab (static electricity is the build-up of electrons on an object -- see Snapshots of Practice, above) was reasonably well-defined, connected (within a particulate model of molecular structure and to observed phenomena), and, viewed in its connections to the molecular model, broad in scope. From a reform perspective, Ingle's lesson was truncated in the same manner as Barry's: she gave the students the concept of static electricity rather than developing it with them. Ingle interacted with students in a manner that seemed to promote student thinking and verbalization of their thinking to her, but there appeared to be somewhat less student-student interaction than in Barry's classroom. The latter impression may be an artifact of the particular lessons we observed, as Ingle gave persuasive descriptions of other lessons that involved far more student discourse and knowledge construction.

Ms. Nelson's lesson was more puzzling. She began the preparation phase by asking students to speculate ("guess") in their journals what components are essential for making a fire ("What things does a fire need?") After students had taken a little time to think, Nelson established through questioning and paraphrasing (e.g., substituting the term "fuel" for "something to burn") that the three essentials were oxygen, fuel, and heat. She showed students how to display these as "the fire triangle" and emphasized that the absence of any one of them would rule out the possibility of fire. Nelson also recalled an earlier demonstration in which she had tried to burn a steel nail and some steel wool, the former unsuccessfully and the latter successfully. Through a combination of questioning and explanation, she established that the thinner strands of steel burned because the oxygen could "get to" the steel more readily. Students then used the "fire triangle" to guide their efforts to make small fires out on the playground. The processing of the activity was brief, consisting mostly of students' narrative (descriptive) accounts of their fire-building efforts. As Ms. Nelson did not either elicit students' ideas nor offer her own explanation on exactly <u>why</u> the elements in the fire triangle were essential or how burning as a process of rapid oxidation actually works, an argument could be made that the lesson's content is basically factual: oxygen, fuel, and heat. We have grouped the lesson with "ideas" partly because the way that Nelson discussed the lesson and related lessons suggested that she was headed toward an explanation of what fire is and how burning works, but we are not fully confident that this categorization is correct.

Ms. Sundmeir's lesson on desert plants (see Snapshots of Practice, above) showed how such plants are adapted to an environment characterized by long dry periods punctuated by sudden brief downfalls. Though Sundmeir said the lesson was about "adaptation," it might be more accurate to say that it was about "adaptedness." That is, there was no discussion or other examination of the processes of random genetic

variation and natural selection through which adaptation occurs, but there was a demonstration or "experiment" to dramatize how the thick skins of cacti, like Vaseline covering a sponge, enable them to retain moisture. Sundmeir's pedagogy was basically presentational and demonstrative rather than constructivist, including little discussion and little attention to the warrant for scientific claims.

Ms. Turnby involved students in a series of experiments meant to test the ecological health of a local river. Students took samples of river water, determined the pH level and temperature, and then related the tests to the sorts of organic life that thrive under certain conditions. Our field researcher's account was persuasive enough to justify classing Turnby with the idea-oriented teachers, but because of a tape recorder failure, we cannot be fully confident of just how well the idea of ecological health was developed, nor of the details of Turnby's pedagogy.

The Pattern in the Patterns

As we have seen, a science of ideas was quite rare in our sample. While five of the twenty two teachers addressed content that might qualify as idea-oriented, only two were clearly dealing in the fundamental, connected ideas proposed by reformers.

Turning to pedagogy, none of the twenty two was teaching in a simple presentational, textbook, and worksheet-dominated style. Nearly all used activities designed to provide students direct, hands-on experience with natural phenomena or designed systems. In lessons that did not involve such activities, teachers used lively narrative or expository texts and/or artwork to vivify instruction. On the other hand, only one or two prepared students for the activities by surfacing and clarifying students' own ideas sufficiently to make it clear how the experience and data from the activities would bear on the validity of their prior knowledge, and these teachers' lessons seemed more fact- than idea-oriented. Prediction, where it was employed at all, was treated almost as a guessing game. Predictions were solicited, but the rationale for them was not. While prediction added dramatic tension to the lessons, it did not prompt students to articulate and crystallize their theories as reformers would advocate. Similarly, there was very little substantive processing of the experience and data derived from the activities, either in the small groups where they were generally carried out or in whole-group debriefing sessions. Sustained student-student discussion focused on making conceptual sense of the activities was even rarer than episodes of Socratic questioning by the teacher.

Thus, few of these classrooms resembled scientific communities, communities of inquirers employing evidence and logical argument to build increasingly accurate (or at least increasingly useful) accounts of how the natural world works. The problems of (1) how to establish appropriate norms of investigation, especially norms of discourse, and (2) how to orchestrate student-student discussions that generate and examine

explanations for observed phenomena appear to be not merely unsolved problems in most classroom, but unrecognized problems, as well.

Many behavioral features of practice commonly associated with the reforms -- hands-on experiences, small groups, prediction, data gathering and display -- were certainly in evidence. What seemed to be missing was a recognition that reformers urge the use of these and other techniques in order to provoke, support, and guide thinking by students. The essence of the new pedagogy is that students must think in order to learn. That is, a real grasp of fundamental, connected ideas is achieved by thinking one's way through problems, puzzles, and confusions rather than simply remembering what one is told. Such thinking, is not to be done by isolated individuals, but by communities of thinking inquirers. Discussion is, if you will, an externalized, social way of thinking things through -- interactive thinking out loud. At key points in the discussion, the teacher may present current scientific accounts of the phenomenon under study, but such presentations should come as answers to questions or solutions to problems that students are actively puzzling over -- thinking about -- not as answers to questions they never asked, about phenomena they never wondered about.

As David Hawkins recognized (Hawkins, 1990), the great pioneer of quantum theory Niels Bohr captured the essence of science with a physicist's characteristic economy:

> The task of science is both to *extend our experience* and *reduce it to order*, and this task presents various aspects, inseparably connected with each other. Only by experience itself do we come to recognize those laws which grant us a comprehensive view of the diversity of phenomena. As our knowledge becomes wider we must always be prepared, therefore, to expect alterations in the points of view best suited for the ordering of our experience.
>
> (Bohr in Hawkins, 1990, emphasis added)

As Hawkins noted, without the extension of experience, its reduction to order is unmotivated -- and, we would add, ungrounded. But without the reduction to order, as we have just pointed out, students are left with impressions, not ideas. Further, in contemporary reformers' view, the process of reducing experience to order -- which includes not only the identification of patterns but also and even more importantly, the formulation of explanations -- is one in which teachers should involve students just as actively as in extending their experience. All of the teachers in our sample seem to appreciate the importance of extending students' experience. Thanks in part to Hawkins and others who led an earlier generation of reform, that message seems to have gotten across effectively. But educating teachers about the importance of engaging students in

reducing experience to order and helping teachers learn how to do so is clearly a task that remains before the current generation of science education reformers.

CONCLUSION

The patterns of practice just outlined reflect significant changes in science education, but at a deeper level certain continuities in American curriculum and teaching -- continuities repeatedly mapped by other observers (Goodlad, 1984; Cuban, 1993; Tyack and Cuban, 1995) -- still predominate. Though a detailed treatment of the influences that account for the recent changes must await further analysis and integration of our quantitative and qualitative data, we can offer some general observations at this point. Drawing largely on interviews with the teachers we observed, we have identified six broad categories of factors shaping the observed patterns of continuity and change in the practice. Through a happy accident of initial consonants along with a little fudging for mnemonic purposes, we propose a "6 P" model: policy, professional, personal, pupils, public, and private. As we shall show, the six categories of influence interact in complex ways.

In policy terms, there can be no question that the combination of the Michigan Educational Assessment Program (MEAP) and the Michigan Essential Goals and Objectives for Science Education (MEGOSE) have teachers' attention and are strongly influencing the topics they address. Mention of the MEAP as a key factor shaping what teachers taught was nearly universal and was often linked with the MEGOSE. The state policy messages sent through MEAP and MEGOSE were often not only transmitted on to teachers by local district administrators, but were also strengthened or "amplified" by district policy. State policy has required local districts to adopt or adapt a model curriculum offered by the state, and in science the model curriculum adheres closely to the MEGOSE. Even where teachers did not cite the MEAP as a central influence on the topics they taught, they generally did mention district policy, and we know from our own earlier research that their districts' curricula are tightly aligned with the topics in the MEGOSE.

Beyond topical alignment, teachers attributed to the MEAP, MEGOSE, and district curriculum a variety of other changes in what and how they teach. Several said that MEAP and MEGOSE, strongly reinforced by district policy, have increased the amount of time they devote to science. One even said that "last year [before state & local policy asserted themselves strongly] I skipped science" but now teach it regularly. Several factually-oriented teachers attributed their use of expository text (e.g., Ingle's on earthworms, Newberry's on bats) to the inclusion on the MEAP of more items requiring students to read and use such text. Both of our procedurally-oriented teachers cited district and/or state pressures to include more hands-on activities in science.

In addition to adoption and distribution of a curriculum aligned topically with the state's, districts also used distribution of materials, regular meetings of science teachers, and professional development to influence teachers' practice. In one district with a strong, well-developed emphasis on science education, roughly monthly meetings of middle school science teachers fortified the message concerning topical coverage and introduced activities and techniques for teachers to use. Teachers reported, however, that the meetings did not alter their basic teaching approach. Another district paid for teachers to attend a 6-month long series of inservice sessions at a technical institute. The sessions emphasized hands-on activities that teachers reported using quite frequently with their students. We classified one of these teachers as fact-oriented and another as procedurally oriented. Carefully-constructed science kits distributed by one district did find their way into use, contributing to teachers' use of hands-on activities but seeming to exert little reform-oriented influence on the kinds of preparation for and processing of the activities that the teachers employed.

Private firms and a foundation made several noteworthy contributions. A major motor company not only developed a series of units that included the skimmers-and-pennies activity that Ms. Isaro employed, but also sent engineers into the classroom to demonstrate how the lessons should be taught. The message Isaro took from the demonstrations and materials, however, seems to have been consistent with her procedural emphasis, and instead of promoting the development of a scientific community in the classroom, the engineers seem to have emphasized the kind of task coordination or teamwork they reported practicing on the job. In another community, engineers from a chemical or pharmaceutical firm helped Ms. Ingle set up her laboratories and actually conducted "clinical interviews" for Ms. Bach. A significant contribution from the Kellogg Foundation is discussed below, in connection with the change in Ms. Barry's teaching, but the Foundation also provided funding for the Michigan Department of Education to develop a series of units illustrating how selected content from the MEGOSE might be taught.

The role of the public (including parents) was not so striking in science as in mathematics (see Spillane and Zeuli, 1997), where one community rose up against the de-tracking of mathematics teaching at the middle school level and succeeded in reinstituting a tracked curriculum. But we should note that one way in which the MEAP influenced many schools and teachers was via the annual reports that state policy requires districts to issue on a school-by-school basis. Those reports include the school's MEAP scores, and from an earlier phase of our research (Spillane and Thompson, 1996), it is clear that concern about parents' and other citizens' response to MEAP scores heightened the attention that district leaders accorded the MEAP and MEGOSE.

A few teachers mentioned their own students ("pupils") as influences. Some said that their students seemed to enjoy hands-on activities far more than the textbook and

worksheet-oriented instruction they had practiced before the recent changes. This seemed to have confirmed the teachers in the changes they had made. But students were an influence in another sense, as well. Most teachers in our sample were inveterate "tinkerers." Asked why they had taught a lesson as they had, they frequently mentioned a bad experience with an earlier version of the same activity and explained how they had adjusted it to suit their students better. They were always adjusting, re-shaping, and rearranging components of practice in response to their own experience with students in the classroom. Many teachers portrayed themselves as the inventors of their own pedagogy -- not at a single go, but through a process of slow accumulation over several years of teaching. They readily conceded that state and district policy set the agenda of topics to be addressed, but often explicitly denied that either had exerted any appreciable effect on the way they actually taught. The changes that most teachers made through tinkering seemed, however, to remain within an overall mode of teaching that remained remarkably constant.

The fifth and sixth sources of influence over practice were the personal and the professional. Who these teachers were as people (personal) strongly affected the way in which all of the other sources of influence affected them. Put differently, personal factors strongly mediated virtually all other sources of influence on teaching practice. This effect is illustrated most clearly in the case of Ms. Barry, the most reform-oriented teacher in our sample. By her own account, in her early years of teaching, Barry was extremely traditional in her approach:

> In the beginning I would have said, "Here's the paper. Everything is set up for you. All you have to do is write the numbers in [for the experimental results]. No thinking involved. You don't even have to look at that paper if you don't want to. You just know where to put the number, or have the person next to you put the number down."

A foundation for understanding the shifts in Ms. Barry's teaching over time is probably her special drive and willingness to dedicate herself to teaching: "I throw myself into my teaching. It's like a hobby." But the interpretation also has its limitations. Early in her career Ms. Barry's drive to succeed was oriented toward what defined success at her school among her older, male, science colleagues -- classroom control, the demonstration of content mastery, the ability to deliver content and arrange laboratory experiments in ways that allowed ambitious students to get good grades by memorizing the content, doing the labs and getting the expected experimental results. Only later, when she had grown confident of her ability to control a classroom, did she begin to rethink her teaching.

Barry portrayed the change as a long, gradual, and very complex one. She rejected the notion that any one episode or incident was a turning point, but among the experiences that prompted the change was a "training session" on student learning:

> Somewhere in one of my training sessions, somebody said something about the percentage of people who actually learn that way, memorizing and abstract. . . I was appalled, because I looked at myself and I said, "Wow!! I'm missing the other seventy some percent or whatever" . . . I can't remember where that happened. It was in one of those workshops where it was just like in black and white that I'm teaching to a small percentage of my learners, ninety percent of the time and not giving the other ones any other way to do it.

Whatever its genesis, the transformation was supported by a broad range of experiences over several years. Contributing to it were courses and workshops at a nearby university with a center for science and mathematics education, participation in a science curriculum change network supported by the Michigan Department of Education out of federal funds (SEMS and SEMS Plus), and involvement in a network of science projects funded by the Kellogg Foundation:

> . . . one of the main things I think that has made a difference was the cluster group that we had for those of us who had Kellogg grants. There were teachers from around the state who got together one or two times a year and met and talked about what's going on in our classroom. And. . . we also got a chance to travel to different school districts. . . . And I think I really learned a lot in those situations where we worked with small groups of teachers. Well, in some cases it was a larger group [who met twice a year]... over a three year span.... for a weekend usually. . . . We would talk about teaching, and problems. Common problems, goals. Ways that we would like to change our teaching practices. We would report to each other on the progress in our home districts, on our various projects. And then later on in the three year time span we started to visit [other] districts to actually see the project. And just getting the teachers together to talk, things would come up that everybody shares.

Generalizing about the professional development experiences that she found most helpful, Barry said:

> I think they would be the ones where the teachers would get together and we would practice the materials. Practice the labs. Gather materials and then go back to classrooms and then come back together again. And talk about ways that things were done in the classroom. And you think, "Oh, I didn't try that, or "That would be a good thing to do." And then talk about the way students respond. Those kinds of experiences. Where you could reflect on something you tried, were the best . . . I haven't had enough of them. It's hard.

Barry's description of genuinely useful professional development experiences for herself parallels the kind of pedagogy advocated for K-12 students by science education

reformers, combining a variety of hands-on activities with opportunities for reflective discussion. We believe that this is not simply a coincidence: the changes in her own teaching that Barry described involved major conceptual reconstruction, supported by both of Niels Bohr's essential elements of science: the extension of experience (visits to other districts, hearing about other teachers' approaches) and the reduction of that experience to order by "reflecting on something you tried." The combination enabled Barry to get beyond tinkering within a fixed mode of practice and to make transformative changes in the mode of teaching, itself.

If Barry, who very actively sought out such experiences -- sometimes traveling as far as the Lawrence Hall of Science in Berkeley to find them -- "hadn't had enough of them," most other teachers in our sample seem to have had too few to make an appreciable difference in their teaching. The one exception may be Ingle, our next most reform-oriented teacher, who told of experiences similar to Barry's, including an opportunity at a national conference to experience learning science herself in the manner she then sought to employ in teaching her own students. Though Barry embraced the MEGOSE and spoke approvingly of the "extra pressure" the MEAP had put on teachers to reform their practice, it seems clear that most of the large changes in her practice resulted from her own initiative and energy and to the professional development experiences, formal and informal, that she sought out or created for herself. These experiences were supported financially by federal, state, and foundation sources, but their character was essentially professional. That is, they were shaped, developed, and conducted by teachers and university-based people whose principal interests were in improving professional practice, not by politicians, state officials, or private executives, who might have had somewhat different motives and purposes.

In some analyses of reform, cases like Barry's are regarded as irrelevant. If the reform of her practice is essentially a story of one teacher's extraordinary personal initiative and energy, the reasoning goes, then that story has nothing to say to policy. Policy is, by its very nature, concerned with broader changes in the system. But we would argue that to dismiss Barry's case as a quirk of personality is a serious error. It is true that the very exceptionality of Barry's case -- only one other teacher in a specially selected sample approaches her level of accomplishment in realizing the reforms -- suggests that federal, state, and local district policy have not yet produced anything like widespread understanding of ideas at the heart of the reforms. But, as we have shown in earlier work (Spillane and Thompson, 1996), intellectual entrepreneurs like Barry, given the right sorts of support by district leadership, can develop networks of similarly reform-minded colleagues across the district. In one of our districts, Riverville, a teacher leader in mathematics education has done exactly that. As a result, a teacher who by her own admission took up the reforms because colleagues all around her were doing so -- not because of any extraordinary initiative or commitement of her own -- has achieved perhaps the fullest realization of reform ideals in mathematics of all the teachers in our sample.

If, as others have argued (Cohen and Barnes, 1993; Ball and Cohen, 1990) and Barry's case tends to confirm, realizing reform in the classroom depends most centrally on a process of professional learning, then the core problem for policy at this point is how to promote such learning on a broader scale. "Scaling up," the vogue term for this challenge, is often discussed as though good practice can, through some process of policy engineering, be xeroxed in quantity -- can be captured, packaged, disseminated, and replicated. We doubt it. Changing practice involves not only behavioral but also conceptual change, and learning for conceptual change, like science, seems to involve both the extension of experience and reflection on that experience to reduce it to order. In other words, the next problem in the reform of science education is a problem of teacher learning, and the question is how to promote effective professional development on a large scale.

Granted, a Barry here and a Riverville teacher leader there are scarcely a basis for widespread reform in science and mathematics education. But developments in other fields, such as writing instruction, may offer clues on how to promote the development of many more Barrys and many within-district teacher networks for science education reform like the Riverville network for reform in mathematics education. In the field of writing instruction, the National Writing Project and similar projects have generated a far-flung network of professional development programs that provide teachers with rich opportunities to experience as learners the kind of pedagogy that reformers in that field advocate for K-12 students. In intensive writing workshops, teachers write about subjects and in genres of interest to them, read and discuss each other's work, and go through iterative processes of revision. The programs often also provide help to teachers in translating what they have experienced as learners into approaches and activities appropriate for their own students, as well as organizing collegial groups through which teachers can continue to support each other, substantively as well as morally, through the change process.

Though not yet so widespread, there are notable examples in mathematics education of professional development programs that provide teachers with analogous opportunities to experience as learners the kinds of mathematics content and pedagogy advocated by reformers. In the Summermath program and programs now based at Education Development Center (Schifter, 1996; Schifter and Fosnot, 1993; Nelson and Hammerman, 1994), teachers get an opportunity, as one Summermath staff member put it, "to construct constructivism" on the basis of their experience as learners. Follow-up support is provided, as well. EDC is also developing and operating programs designed to help administrators learn what they need to know to support reform-minded teachers' development. Such support was crucial in the Riverville case.

It may be that analogous programs are beginning to emerge in science education, within Michigan and elsewhere. But they do not seem common at present. We would suggest

that building the capacity to provide this sort of professional development -- which will, itself, require extensive learning by providers of professional development -- is the next major task for the reform movement in science education.

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