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The Ideal of Standards and the Reality of Schools: Needed Research

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Abstract: Research potentially can assist in the process of implementing the National Science Education Standards. Existing research shows that changes called for in the Standards are difficult to put into practice, create dilemmas for teachers, require significant changes in teachers' values and beliefs, are fostered when change is pursued within departments within schools, are influenced powerfully by teacher collaboration in the work context, are often resisted strongly by parents, and often demand new student roles and different student work. The results of research on reform do not give a definitive picture of the most productive roles for students, the nature of the desired student work, how teachers can best be engaged in reassessing values and beliefs and taking responsibility for acquiring new professional competencies, how to realize "science for all," and the most effective ways of involving parents. Research is needed which will: (1) be approached from multiple perspectives, (2) be conducted in the "real world," (3) focus on interventions into conventional school practice, (4) not assume change can be driven from the top down, (5) be interpretive in nature, (6) focus on student roles and student work, (7) give major attention to teacher learning, (8) attend to parents' concerns, and (9) be approached systemically. © 2000 John Wiley & Sons, Inc. J Res Sci Teach 38: 3–16, 2001

Goals and standards for science education have been established; the big challenge is implementing them. The *National Science Education Standards* (National Research Council, 1996) presents a vision for science education that is both exciting and viable, but the actions needed to put the standards into widespread practice have many facets and varied support among the many people responsible for them.

Context

The context in which these standards are expected to take root is complex and not fully understood. The processes by which significant changes can be made in this "real world" situation share in this complexity and lack full understanding. The tendency of the person interested in reform is to think about the situation in terms of some element thought to be especially important, such as the curriculum content, particular instructional practices, the educational goals pursued, the assessment practices employed, the prior conceptions of the

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students, the educational background of the teachers—and the list goes on. The difficulty is that big changes in any one of these elements, by themselves, are not sufficient to produce major reforms. Somehow, the person wishing to bring about significant educational reform—such as putting into practice the major elements of the *National Science Education Standards*—must come to grips with the totality of this complex situation in a manner that few policy makers, administrators, practitioners, or researchers ever seem to do.

In addition to the complexity itself, our ways of understanding these complex educational settings are many and varied. Any given educational setting has, for example, a cultural dimension with many interacting cultural components that vary considerably from one locality to another. The school culture, including its science teacher subculture, interacts with the broader community culture and its expectations for what schooling should do for its younger members. Schooling also has an economic dimension; changes in educational practice almost always have financial implications. And financial issues—as well as cultural issues—are worked out in the political arena. Power is exercised in a multiplicity of ways in the politics of schools, communities, and governmental bodies. These socio-cultural, economic and political forces act and interact to influence schools and the dynamics of classrooms—the settings where the learning processes occur.

These ways of understanding are tied to what we can call research perspectives. It is helpful to talk about research as being done from a variety of perspectives, but it is necessary to define what is meant by a "research perspective." They are diverse. There is no official taxonomy of these perspectives, although there is a somewhat common pattern of terminology. Reference commonly is made to a psychological perspective or a socio-cultural research perspective, for example. But what constitutes a research perspective? It has many facets, including a chosen dimension of an educational setting to study, a theoretical vantage point from which the setting is viewed and analyzed, a category of variables to be examined, and a methodology, or class of methodologies, to employ.

Psychological perspectives have dominated educational research through most of its history and illustrate the situation. Persons approaching their research from this perspective have chosen to focus on the mental processes of the people in the educational setting, whether these mental processes be those of the students or the teachers. Choices of necessity have been made and many other facets probably have been left out of the picture, such as the culture, social patterns, the financial aspects or the political aspects of the setting. The researcher assumes that mental processes are of major importance and that much will be learned about the total situation by understanding more about this aspect. The research methodologies and instrumentation accepted by psychologists are chosen to pursue the research. The research findings will be interpreted within theoretical frameworks accepted by psychologists.

But to say that particular research is being pursued from a psychological perspective does not tell the whole story. There currently is much debate, for example, between different camps within this perspective. There are important differences between adherents of a cognitive perspective and a situated learning perspective and each one of these labels (i.e., cognitive and situated learning) encompasses an array of positions (Cobb & Bowers, 1999).

While recognizing that any listing of research perspectives is to a certain extent idiosyncratic and has varied levels of refinement, it is useful to describe briefly a few such perspectives here as context for our examination of research on fostering educational change. In addition to the various psychological perspectives, there is a collection of perspectives we can label as socio-cultural. Within this broad category we include, among others, research that focuses on culture and uses the ethnographic methods of anthropologists and research that addresses social dynamics and brings to bear the theoretical perspectives of sociology. Yet another research perspective is a political perspective—one that views a situation from the standpoint of power: who holds power, how power is exercised, and how conflicting power claims are resolved. Many educational reform endeavors cannot be understood without viewing them from a political perspective—a situation well illustrated by the recent political battles over science and mathematics in California. While widely reported in the media, these battles still await the more reflective examination of researchers who investigate the situation from a political perspective.

Scholarship is not limited to empirical study. Another form of scholarship with insights on the enterprise of changing educational practice to be more consistent with accepted standards is philosophical analysis. What are the premises upon which the standards are based? If the *Standards* are accepted, what are the implications for the learning of different student groups, what student outcomes can be expected, and what are the societal implications? The results of such analyses obviously will vary with the philosophical perspective employed in the analyses.

This sketchy overview of forms of scholarship and their potential contributions to science education reform could go on, but it is sufficient to illustrate both the complexity of the situation under consideration here and the multiplicity of scholarly perspectives and methodologies with potential for illuminating the situation. We will return to this topic later when addressing needed research. Before moving on, however, it is important to express a viewpoint now that colors much of the discussion that follows. We proceed from the conviction that the most fruitful approaches for the future are those that are the most *holistic* and *systemic*. Scholarship must be holistic in the sense of giving *simultaneous* attention to all of the many elements and perspectives that are part of the picture. They must be systemic in that attention is given to the many *interactions* among the various elements and the influence they have on each other.

The Challenge

The challenge for the research community is to identify the most critical aspects of the needed research, marshal the forces to do it, and provide to the educational community the research-based information it needs to move forward with science education reform. Although there are significant gaps in our knowledge of the science education reform process, the existing body of research gives us a fairly clear picture of many aspects of the current situation and highlights specific areas where additional understanding is of central importance. Appropriate research, grounded in our current knowledge, has the potential of filling some of the gaps in our understanding and providing a basis for implementation efforts that lead to significant reform.

In meeting this challenge, the previously mentioned holistic and systemic views are crucial. While a systemic view quickly establishes that there are no simple solutions in the process of reform, one would expect that there are some very strategic leverage points. An old rule of thumb known as Pareto's principle (named for an Italian economist of an earlier era) says that 80% of the results of an endeavor are produced by only 20% of the input efforts of the endeavor. With the fuller understanding of reform that research provides, reformers may be in a better position to identify these strategic leverage points—that is, particularly productive entry points to the complex system—and take productive action. This systemic outlook, with concomitant attention to finding strategic leverage points, informs our analysis.

In the sections which follow we give attention to what research says about what we already know, what we do not know, and thus where research has the greatest potential for furthering the reform of science education. Because of the need for a systemic and holistic view of the situation, much of the research cited is socio-cultural and built upon qualitative research techniques. Research of this nature tends to examine all facets of a situation, including the

political dynamics, the learning processes, and the philosophical (including ethical) issues involved in the situation under study. While much of what is presented below concerning science education reform is from case study research and related qualitative investigations of situations in which reform was being pursued, the most valuable research related to reform in the future may or may not be conducted within such a perspective.

What We Already Know

A "big picture" perspective on the extant research points to the following conclusions about efforts to introduce changes of the type advocated in the *National Science Education Standards*.

The dramatic changes called for in the new Standards are very difficult to put into full practice and where attempted generally fall far short of the mark.

Numerous research studies point to the difficulties teachers face as they attempt to change their practice in any area of schooling. They experience pressure from school districts and parents for students to score well on standardized exams, feel inadequately prepared to try new ways of doing things in their classrooms, and have a limited understanding of the change process, in general. Change is complex, and efforts to simplify the process often derail or limit the success of long-lasting reform (see e.g., Fullan, 1991, 1993; Sarason, 1990, 1996).

Studies conducted specifically in the area of science have yielded the same general conclusion. It is evident in reviews of the research in this area (Anderson, et al., 1994) and it is clear in recent case studies (Anderson, 1996) of schools initiating changes of the type advocated in the *National Science Education Standards*, as well as schools pursuing changes recommended in the NCTM *Standards for School Mathematics* (1989). The curriculum approaches and orientations to teaching and learning embedded in much of the new *Standards* are exceedingly difficult to place into widespread practice in the schools.

The difficulties of making the desired changes are highlighted by the many dilemmas teachers face in the process.

While the classic definition of a dilemma pertains to a situation with two alternatives—neither of which is totally acceptable—the word can also be used to address even more complex situations, that is, ones with several alternative courses of action, each of which has undesirable results along with the desired ones. Some of the dilemmas science teachers experience are described in the case studies referred to above (Anderson, 1995a, 1996.)

1. *Time*. Teachers never have enough time to teach everything they think is important. The reforms called for in the new *National Science Education Standards* include additions to the typical existing curriculum—as well as deletions—and teachers are faced with choices they find difficult to make.
2. *Ideal vs. reality*. Teachers find a tension between the ideal portrayed in the new *Standards* and what they perceive to be the realities of their classroom. Change is not easy.
3. *Changing roles and work*. Current roles of students and the nature of the work they do is deeply ingrained in the school culture. Teachers find it difficult to counter the existing school culture and adopt new roles for themselves—roles which in turn encourage the desired student roles and work.
4. *The preparation ethic*. Preparation of students for the next level of schooling is so deeply ingrained in the culture of science departments that teachers find it difficult to implement many of the new *Standards* due to their perception that preparation might suffer. Although empirical research indicates these fears are largely groundless, teachers nevertheless experience it as a dilemma.
5. *Equity*. Related to the preparation ethic is teachers' concern about what is meant by "science for all." Many teachers see a tension between teaching all students—including some they perceive to be uninterested or unable to achieve at desired levels—and providing to the more able or willing student the high level of instruction called for by the *Standards*. Debates over tracking and ability grouping are part of the discussions surrounding this issue.

Dilemmas such as the above also are apparent in a recent study of the California science education reform efforts. It indicates that as teachers attempt to implement integrated science in their programs to replace the familiar "layer cake" structure of the curriculum and increase their percentage of "hands-on" instruction, they are faced with a host of challenges (Atkin, Helms, Roseik, & Siner, 1996). First, how will the content be sequenced? Will there be enough depth? How does one integrate such different fields as physics, chemistry, and biology while maintaining the integrity of the individual subjects? How can the majority of instruction be "hands-on" and still be meaningful? As teachers work to make substantive changes in their practice, serious issues related to the nature of science, knowledge of science subject matter, pedagogy, and identity come to the fore.

Fundamental reform of this nature requires significant changes in teachers' values and beliefs about science education practice.

The previously cited case studies (Anderson, 1996) contain numerous illustrations of the central role of teachers' values and beliefs in their attempts to initiate change. The cross-site analysis of the cases also pointed to the necessity of changes in teachers' values and beliefs to bring about changes in classroom practice.

Grossman and Stodolsky (1995) argue that attempts to reform secondary schools will fall short if the beliefs, norms, and practices of the high school subjects are not taken into full account. In their research, they conclude that teachers' professional identity is permeated by their beliefs about the nature of the subject matter. This endpoint, or a subject subculture, is the result of their own education, beginning with the undergraduate major and extending to career-long professional development activities. The subject, these authors claim, is a crucial context, or "commonplace," in the daily work-lives of teachers.

Most of the literature on teachers' beliefs about the nature of science is based on two important assumptions: (1) what teachers believe about the nature of science affects their behavior in the classroom, and (2) what teachers believe about the nature of science affects their students' conceptions of the nature of science. The few studies that have attempted to examine these assumptions provide conflicting results. Some studies conclude that no relationship exists between teachers' understanding of the nature of science and their practice, while others suggest teachers exhibit instructional behaviors consistent with their beliefs (Lederman, 1992). For example, Duschl and Wright (1989) found that teachers generally did not consider the nature of the subject matter in making their instructional decisions, while both Brickhouse (1990), and Russell and Munby (1989) found that teachers' beliefs about the nature of science have a considerable impact on their classroom practice. Still other studies posit that teachers' beliefs about the nature of science are implicitly communicated by the language they use in presenting subject matter and the types of activities they emphasize (Russell & Munby, 1989; Zeidler & Lederman, 1987). In another paper, Koulaidis and Ogborn (1995) call for a reexamination of teachers' philosophical assumptions about science. They urge researchers to pursue studies that explicate the ways in which teachers' philosophies of science relate to teachers' views of school science and pedagogy.

Possibly of even greater influence are teachers' beliefs about the importance of preparing students for the next level of schooling (the "preparation ethic") (Mitchener & Anderson, 1989),

their beliefs about the viability of pursuing the teaching of "science for all," (i.e., whether all children can learn science) and the nature of instruction appropriate for students of various backgrounds, abilities, and interests. Teachers' beliefs have a powerful influence in such matters and major changes in their practice are unlikely to occur without concomitant changes in what they value and believe.

Finally, recent research exploring science teachers' perceptions of students and students' experiences in science classes suggests a relationship between teachers' views of students in terms of ability, gender, and race and their pedagogical decision making (Bianchini, Cavazos, & Helms, 1999). Hence, particularly with respect to the instructional issues related to equity in diverse teaching settings, teachers' beliefs about students' experiences, backgrounds, and abilities are important considerations when attempting to implement an innovation such as the *Standards*.

Departments within schools are the most important setting for change, although most research addresses whole school change.

Much of the change literature focuses on whole school change. Significant and lasting change, however, requires intensive efforts at the department level. The case studies cited above consistently showed that the process of change within senior high schools was occurring within the subject matter departments (Anderson, 1996). Talbert (1994) points to the power of the subject department in forging professional community. She suggests that teachers' professional lives form within "multiple embedded contexts," with the subject department as primary. While this and other research (Grossman and Stodolsky, 1994; Little, 1993; McLaughlin, 1993) point to the subject departments as an important context for teacher development, there are issues related to the subject that create barriers to that change. Moreover, even when science teachers are willing to work within a new reform, the actual character of activities in which their students engage often looks more like the old than the new (Anderson, 1996).

Substantial teacher collaboration in the work context—not just in in-service education—can be a powerful changing influence on teachers' values and beliefs.

In case studies conducted of schools selected from across the country on the basis of their progress in reforming science or mathematics instruction, the most powerful influence for change identified was collaboration among teachers in the day-by-day work context. This was the context in which assumptions, values, and beliefs were challenged as teachers made decisions about immediate and specific curriculum and instructional matters (Anderson, 1995a, 1996). Since so much of what is advocated as reforms (e.g., in the *National Science Education Standards*) is understood by its audience only in the abstract without a clear understanding of how it appears in practice, practitioners are left with a large amount of understanding which they must construct without sufficient assistance from the advocates of the reform. Collaborative work settings appear to be a context in which this construction of understanding can truly occur.

In his book *Change Forces*, Michael Fullan (1993) suggests that personal vision-building, inquiry, mastery, and collaboration represent the "four core capacities" needed for substantive and lasting change. A significant barrier to substantive change comes from a lack of attention to the ways in which teachers come to hold certain beliefs, values, and assumptions with respect to students' roles, pedagogy, and the science curriculum.

Implications of this view of the teachers include a necessity to move away from inservice education done in isolation and conduct it in the context of broader education change endeavors (Anderson, 1997). It also suggests that people interested in subject matter reform, in particular the successful implementation of the new *National Science Education Standards*, must think differently about the ways in which teachers are engaged with the *Standards*. New forums are needed for teachers to read, reflect, discuss, experiment, and collaborate with the goal of changing what and how they teach.

Teachers working together in collaboration toward similar goals represent the most effective path to change. Science teachers, while they all most certainly do not hold the same or even similar philosophies, do exhibit what Little (1994) calls a "consciousness of kind" which can provide an important starting place in collaborative reflection (see Helms, 1996; also see Groarke, Ovens, & Hargreaves, 1986; Nolfke & Zeichner, 1987; Tukinoff, Ward, & Griffin, 1979; all cited in Richardson, 1994).

In many quarters it is popularly accepted that the new forms of assessment provide a major leverage point for fostering reform, but the case studies of successful reform efforts cited above did not find new assessments to be a major impetus for reform. Teachers often talked about new forms of assessment appearing in schools, but it was more likely to be in terms of "something else" with which they had to cope, not something that was promoting positive changes in curriculum or instruction. In political circles, it is common to adopt the assumption that new and improved assessments will drive reform and turn this assumption into a conclusion. The case studies did not support this assumption about assessment, but they did provide evidence that teacher collaboration can foster reform.

Parents often resist reforms and they have a strong influence on science education reform efforts; without local parental support of the reform ideas and practices, their implementation falls short.

The power of parents' support—or even more obviously, the power of their resistance—regarding science education reforms is striking in case studies (Anderson, 1996.) This phenomenon was apparent in the mathematics cases as well and is obvious in a number of other studies in mathematics (e.g., Peressini, 1996, Romagnano, 1994). It is clear that teachers wishing to make significant changes must address the assumptions, values, and beliefs, of parents in the process.

The recommended reforms demand new student roles and different student work. It is the "bottom line" of science education reform and it is the area in which almost all reforms fall short, even when teachers have made substantial changes in their own roles and practice.

The case studies of schools selected because of their progress in improving science education showed that the required changes (in student roles and the nature of the work the students do) were never realized as fully as the stated reforms would suggest. Even when teachers resolved some of their dilemmas and made significant shifts in values and beliefs, generally only modest progress was made in carrying the reforms to this expected student endpoint (Anderson, 1996). This finding is consistent with what other studies of general school reform have found.

Science education reform, especially as outlined by the *National Science Education Standards*, emphasizes the importance of active learning as a means to achieve the goals the reforms set forth. The science education reformers urge educators to provide students with inquiry experiences that allow students to participate in a community of scientific practice (AAAS, 1989; CA Dept. of Ed., 1990; NRC, 1996; NSTA, 1992). The challenge, however, comes when we hear the thud of the closing of the classroom door and the teacher begins working in isolation from his or her peers.

What We Do Not Know

The research cited above also identifies a number of matters about which we do not have a good understanding. These topics constitute areas of understanding important to practitioners and policy makers; they deserve thorough investigation.

The most productive roles for students when addressing science content in ordinary classroom settings are not known in any practical detail.

While some researchers such as Minstrell and Stimpson (1993) have done important research on the roles of teachers and students in a science class, detailed understanding is needed of what role students can play in varied science classroom contexts. The modes of learning called for in the new *Standards* imply markedly different roles for the students in terms of designing laboratory investigations, processing information and engaging in such mental processes as interpreting, explaining, and hypothesizing. Given the knowledge we have, it is clear that these roles cannot be studied very effectively in isolation because their implementation interacts so deeply with changes in teachers' roles and various teacher values and beliefs. The new student roles must be studied in the context of teachers initiating change in a "real world" setting.

In addition to student roles, the nature of the desired student work and the means of engaging students in it within ordinary classroom contexts, is not known in any practical detail.

The student roles described above imply that students will direct much of their own learning—including designing and directing various tasks—that these tasks will vary among students, and that these tasks will emphasize reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures, and explaining complex problems. The range and nature of these tasks in various specific science contexts are not well understood; in fact, there is a dearth of studies on desired student work. As in the case of student roles, these matters must be studied in the context of ordinary teachers attempting to initiate them while implementing the new *Standards*.

The popular label, constructivism, could conveniently be used in this context, although it is a term not used in the *National Science Education Standards*. Another appropriate term, inquiry, of course is prevalent in the *Standards*. It is used there in at least three different senses: inquiry as a descriptor of scientific research, inquiry as a type of teaching, and inquiry as a mode of student learning. This mode of learning implies certain student roles and type of work; understanding what is really meant by inquiry learning is the issue at hand. We need to understand it not just in a psychological sense, but in actual classroom terms that include specifics about student roles and their work, as well as how teachers teach in a manner that influences such roles and work in the manner intended by the *Standards*.

How teachers can best be engaged (over a period of years) in reassessing their personal values and beliefs and taking major personal responsibility for acquiring needed new professional competencies is not well understood.

From the standpoint of a policy maker, a major issue is how to foster teacher collaboration in the day-to-day work context that will eventually reach the "bottom line" of student roles and work. The research tells us that teacher collaboration is powerful, but it has not been studied as a specific means of addressing these particular aspects of science education reform. To be fully understood, this situation must be studied from multiple perspectives, in particular from psychological and socio-cultural perspectives. Furthermore, this research must be pursued within particular subject matter contexts.

It is not clear how to involve parents most effectively in the science education reform process so that they are educated about the issues involved and can influence their children's education most positively.

It is clear that parents can have a strong influence on efforts to change science education practice in a given school, but there is not a significant research base for deciding on the best course of action for schools to take to see that this influence is enlightened, well-considered and brought into school processes in a manner that is both authentic and of assistance in the reform process. The research indicates teachers provide a key interface for this interaction between

parent and school. Given the critical role of teachers in science education change, it appears to be important to consider this matter in the context of studying the change process within a science department.

Characteristics of Needed Research

Given the current state of knowledge as outlined above, a case can be made that the most promising research in this area will: (1) be approached from multiple perspectives, (2) be conducted in the "real world," (3) focus on interventions into conventional school practice, (4) *not* assume that change can be driven from the top down, (5) be interpretive in nature, (6) focus on student roles and student work, (7) give major attention to teacher learning (which includes addressing values and beliefs), (8) attend to parents' concerns, and (9) be approached systemically.

Multiple Perspectives

The desired research needs to be broad and comprehensive in the sense of being approached from a multiplicity of perspectives (e.g., psychological—both cognitive and affective—sociological, cultural, organizational, political, economic, philosophical, and subject matter). Each of these theoretical perspectives is important, but each one by itself is inadequate for fully understanding the matters at hand. Although some researchers have pursued research from more than one perspective (e.g., Eisenhart & Borko, 1993, address classroom research simultaneously from psychological and cultural anthropological perspectives) the multiplicity of relevant perspectives is such that little research actually brings to bear the range of perspectives needed. While some broad-based research can be anticipated, much in the way of new understandings will have to come from scholarly synthesis of studies conducted from various perspectives.

Occasional studies conducted from a particular perspective contribute rather directly to a broad picture. For example, research by Lave and Wenger (1992) points to knowledge being socially constituted; that is, learning cannot be separated from the context in which it takes place. They add to common interpretations of situated learning by drawing attention to the point that "learners inevitably participate in communities of practitioners and that the mastery of knowledge and skills requires newcomers to move toward full participation in sociocultural practices of a community" (p. 29). They define a community of practice as

> a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice. A community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage. (p. 98)

From this perspective, *both* science classrooms and science teachers are communities of practice. That is, there is a sense in which science classrooms, with their particular set of relations to persons, activities, and knowledge, exist as communities of practice. Likewise, the professional community of science teachers also exists as such, with its own set of relations. Looking at classrooms through this lens provides a fuller picture of the nature of the relations among the teacher, the students, and the subject matter and the ways in which all three contribute to the various roles each plays in classroom settings. We need more research that holistically informs our relatively poor understandings of the meaning of "science for all."

Conduct Research in the "Real World"

If the intent is to understand how the new *Standards* can be implemented, it will be necessary to conduct research in ordinary school settings. Research already shows that given the right circumstances reform can occur in special settings with the support of experts and extensive resources (Anderson, 1994, 1996). Studies are needed in ordinary school contexts, with ordinary levels of resources, and ordinary outside help.

Study Interventions

Within these ordinary contexts, researchers need to study a variety of specific interventions having certain intended outcomes. These interventions should include those influencing parents, teachers, and students. In particular, interventions chosen and initiated by teachers must be central to this research. To learn more about the challenges and dilemmas they face, teachers must play a large role in shaping their new goals and implementing their new practices. This is not a research role for the teachers, but a professional development and leadership role for them. Upon viewing the results of prior research, and the recommendations found in the *National Science Education Standards*, teachers are the ones who must decide what student roles and work will be pursued in their own classes. In keeping with the results of past research, this work should occur in a highly collaborative teacher planning context. Teachers must be encouraged to confront their personal values and beliefs as they relate to the reforms recommended in the *Science Standards*. There is a great need for researchers to study such teacher-centered change processes.

Not Based on Assumption that Change Comes from the Top Down

The research must not be based on the misconception that the desired change can be driven from the top down, or that it can be standards and/or assessment-driven. This is not to say that standards, such as the *National Science Education Standards*, do not have a valuable role to play, as research has demonstrated (Anderson, 1996). It is quite different, however, from treating them as an intervention, even in combination with high-stakes testing. While large numbers of political leaders assume a powerful influence for such top-down interventions, it is hard to find research evidence to support the assumption. Awareness of this lack of support for the assumption is beginning to spread through the professional literature as becomes apparent by perusing the 1999 and 2000 issues of *Phi Delta Kappan* and *Educational Leadership*. The inadequacies of interventions that are solely top-down are well established in the research literature (Fullan, 1993; Sarason, 1996).

Interpretive Research

The multiplicity of interacting variables in the matters under study is such that controlled experiments with full prior delineation of all variables are largely impossible. It is important to study the dynamics of the interrelationships of the many factors influencing the total situation. The goal is to make interpretations of this complex situation that will make it possible to assist practitioners in changing practice and aid policy makers in setting better policy. This need places a premium on research that attends to the many relevant variables, their interactions, and various interpretations of the complex situations.

Focus on Student Roles and Student Work

Prior research identifies the role played by students in the classroom and the nature of the work they do as the "bottom line" of educational reform. They are at the heart of the reforms promoted by the new *Standards*, yet the specifics of these desired roles are not well understood nor is the nature of the most beneficial student work clear. Even taking a constructivist orientation as a given, the nature of student roles and work are understood only in broad outline. These matters must be at the center of research in this area.

Give Major Attention to Teacher Learning

Past research points to teacher learning as being central to reform. This teacher learning is foundational for changes in student roles and work. Past research also establishes that the most important of this teacher learning is not in the arena of knowledge and skills, but in the arena of values and beliefs. While it is clear that changes in teacher values and beliefs are central to reform, the nature of these changes and the circumstances under which teachers personally can best reassess these values and beliefs are not fully understood. Just as with student roles and work, these matters must be a major focal point of research in this area (Anderson, 1995b; Parsons, 1995).

Attend to Parents' Concerns

Resistance to the orientation of the new *Standards* on the part of a significant number of parents is apparent in many studies of reform. Under what circumstances (i.e., with what interventions) can parents best participate and learn—including reassessing their values and beliefs—so that they can be effective partners in the reform process?

Approach the Research Systemically

Given the breadth of the key factors identified above, and the relative scarcity of instances of fundamental, department-wide, science education reform, it is clear that research in this arena must be approached systemically. It must be systemic in the sense of simultaneously addressing all major aspects of the system under study, and be approached from the multiple perspectives needed to understand it in all its complexity. It must attend simultaneously to such central matters as students' roles and work, and to teachers' roles, values, and beliefs. The interactions among all of these factors heightens the need for a systemic perspective.

Is It Time For Action Or More Research?

It is time for *both* action to implement reforms according to the *National Science Education Standards* and research to study the process of reform. They should go hand in hand. We have enough research-based knowledge to set off on the path of reform with considerable confidence about what needs to be done. Research also tells us the task is formidable and challenging and needs to be approached with care and diligence.

At the same time, more research is needed as described above. It is important to take full account, however, of the need for this research to be conducted in ordinary school contexts with unexceptional levels of resources. It needs to be conducted in the very settings where major changes in school practice are being pursued. It also needs to be conducted in diverse settings

with the full range of challenges education faces. There is a clear need for collaboration of another kind—collaboration between action-oriented reformers who are working "in the trenches" and skilled researchers who are prepared to conduct their research in these same settings.

References

Atkin, J.M., Helms, J.V., Rosiek, G.L., & Siner, S.A. (1995). Building on strength: Changing science teaching in california public schools. Draft manuscript.

American Association for the Advancement of Science (1989). Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology. Washington, DC: AAAS.

American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press.

Anderson, R.D. (1995a). Curriculum reform: Dilemmas and promise. Phi Delta Kappan, 77, 33–36.

Anderson, R.D. (1995b). Teachers as learners in the context of curriculum reform. A paper presented at the annual convention of the American Educational Research Association in San Francisco, CA on April 20, 1995.

Anderson, R.D. (1996). Study of curriculum reform. (Volume I of the final report of research conducted under contract no. RR91182001 with OERI, U.S. Department of Education). Washington DC: U.S. Government Printing Office (ISBN 0-16-048865-6).

Anderson, R.D. (1997). Professional development for science and mathematics teachers in a time of educational reform and new standards. In Reform in Math and Science Education: Issues for Teachers, 2(1). Columbus, OH: Eisenhower National Clearinghouse for Mathematics and Science Education.

Anderson, R.D., et al. (1994). Issues of curriculum reform in science, mathematics and higher order thinking across the disciplines. Washington, DC: U.S. Government Printing Office.

Bianchini, J.A., Cavazos, L.M., & Helms, J.V. (1999). From professional lives to inclusive practice: Science educators' views of gender, ethnicity, and science. Paper presented at the American Educational Research Association conference in Montreal, Canada.

Brickhouse, N.W. (1990). Teachers beliefs about the nature of science and their relationship to classroom practice. Journal of Teacher Education, 41, 53–62.

California Department of Education. (1990). Science framework for California public schools kindergarten through grade twelve. Sacremento, CA: Author.

Cobb, P., & Bowers, J. (1999). Cognitive and situated learning perspectives in theory and practice. Educational Researcher, 28(2), 4–15.

Cochran-Smith, M., & Lytle, S.L. (1993). Inside/outside: Teacher research and knowledge. New York: Teachers College Press.

Cuban, L. (1988). A fundamental puzzle of school reform. Phi Delta Kappan. 69(5), 340–344.

Cushman, K. (1990). Practice into theory: Teachers coaching teachers. Horace. 7(2), 1–8.

Duschl, R., & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. Journal of Research in Science Teaching. 26, 467–501.

Eisenhart, M., & Borko, H. (1993). Designing classroom research: Themes, issues, and struggles. Boston: Allyn and Bacon.

Fullan, M.G. (1991). The new meaning of educational change. New York: Teachers College Press, Columbia University.

Fullan, M.G. (1993). Force changes: Probing the depths of educational reform. London: The Falmer Press.

Gallagher, J.J. (1991) Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. Science Education, 75, 121–133.

Groarke, J., Ovens, P., & Hargreaves, M. (1986). Towards more open classrooms. In D. Hustler, A. Cassidy, & E. C. Cuff (Eds.) Action research in classrooms and schools. London: Allen and Unwin.

Grossman, P.L., and Stodolsky, S.S. (1994). Considerations of content and the circumstances of secondary school teaching. Review of Research in Education, 20, 179–222.

Grossman, P.L., Stodolsky, S.S. (1995). Content as context: The role of school subjects in secondary school teaching. Educational Researcher, 24, 5–11.

Helms, J.V. (1995). Speaking of the Subject: Science Teachers Reflect on the Nature of Science, Science Teaching, and Themselves. Unpublished dissertation.

Hodson, D. (1993). Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: Some preliminary findings. Interchange, 24, 41–52.

Hollingsworth, S., & Sockett, H. (1994). Teacher research and educational reform. Ninety-third Yearbook of the National Society for the Study of Education. Chicago: University of Chicago Press.

Koulaidis, V., & Ogborn, J. (1995). Science teachers' philosophical assumptions: How well do we understand them? International Journal of Science Education, 17, 273–283.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Press.

Lederman, N. G. (1992). Students' and teachers' conception of the nature of science: a review of research. Journal of Research in Science Teaching, 29, 331–359.

Little, J. (1993). Professional community in comprehensive high schools: The two worlds of academic and vocational teachers. In J.W. Little & M.W. McLaughlin (Eds.), Teachers' work: Individuals, colleagues, and contexts (pp. 137–163). New York: Teachers College Press.

McDonald, J.P. (1993). Steps in planning backwards: Early lessons from the schools. Unpublished manuscript. Providence RI: Coalition of Essential Schools.

McLaughlin, M.W. (1993). What matters most in teachers' workplace context? In J.W. Little, & M.W. McLaughlin (Eds.), Teachers' work: Individuals, colleagues, and contexts (pp. 79–103). New York: Teachers College Press.

Minstrell, J., & Stimpson, V. (1993). Creating an environment for restructuring understanding and reasoning.

Mitchener, C.P., & Anderson, R.D. (1989). Teachers' perspective: Developing and implementing an STS curriculum, Journal of Research in Science Teaching, 26, 351–369.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Science Teachers Association. (1992). Scope, sequence, and coordination of secondary school science. Volume II: Relevant Research. Washington, DC: Author.

Noffke, S.E., & Zeichner, K.M. (1987). Action research and teacher thinking: The first phase of the AR project at the University of Wisconsin, Madison. Paper presented at the annual meeting of the American Educational Research Association, Washington DC.

Parsons, B.A. (1995). Contrasting learning conditions for teachers and students. A paper presented at the annual convention of the American Educational Research Association in San Francisco, CA on April 20, 1995.

Peressini, D. (1996). Parents, power, and the reform of mathematics education: An exploratory analysis of three urban high schools. Urban Education, 31, 3–28.

Richardson, V. (1994). Teacher inquiry as professional staff development. In S. Hollingsworth, & H. Sockett, (Eds.), Teacher research and educational reform. Ninety-third Yearbook of the National Society for the Study of Education (pp. 186–203). Chicago: University of Chicago Press.

Romagnano, L.S. (1994). The dilemmas of change: A tale of two mathematics teachers. Portsmouth, NH: Heinemann.

Russell, T., & Munby, H. (1989). Science as a discipline, science as seen by students and teachers' professional knowledge. In R. Millar (Ed.), Doing science: Images of science in science education (pp. 107–125). London: Falmer Press.

Sarason, S.B. (1990). The predictable failure of educational reform. San Francisco: Jossey-Bass.

Sarason, S.B. (1996). Revisiting "The culture of the school and the problem of change." New York: Teachers College Press.

Schon, D.A. (1987). Educating the reflective practitioner. San Francisco: Jossey-Bass.

Talbert, J. (1994). Boundaries of teachers' professional communities in U.S. high schools: Power and precariousness of the subject department. In L.S. Siskin & J.W. Little (Eds.), The high school department: Perspectives on the subject organization of secondary schools. New York: Teachers College Press.

Tobin, K. (1994). The practice of constructivism in science education. Washington DC: AAAS Press.

Tukinoff, W.J., Ward, B., & Griffin, G. (1979). Interactive research and development on teaching study: Final report. San Francisco: Far West Laboratory.

Tyack, David, & Cuban, Larry. (1997). Tinkering toward Utopia. Cambridge, MA: Harvard University Press.

Zeidler, D.L., & Lederman, N.G. (1987). Science teachers' conception of the nature of science: Do they really influence teaching behavior? Science Education, 71, 721–734.