DOCUMENT RESUME

ED 340 606 SE 052 548

AUTHOR	Shymansky, James A.; Kyle, William C., Jr.
TITLE	Establishing a Research Agenda: The Critical Issues of Science Curriculum Reform. Report of a Conference Held at the Annual Meeting of the National Association for Research in Science Teaching (Atlanta, Georgia, April 8, 1990).
SPONS AGENCY	National Association for Research in Science Teaching.; National Science Foundation, Washington, D.C.
PUB DATE	Mar 91
NOTE	58p.
PUB TYPE	Collected Works - Conference Proceedings (021) -- Viewpoints (Opinion/Position Papers, Essays, etc.) (120)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*Curriculum Development; *Educational Improvement; Elementary Secondary Education; *Research Needs; *Science Curriculum; Science Education

ABSTRACT

In April 1990 a group of 30 educational researchers, sociologists, scientists, analysts, and fund agency staff convened for a meeting to discuss issues critical to science curriculum reform. The meeting, stimulated by national calls for science curriculum reform to prepare a scientifically literate citizenry, had as its objective to generate a research specifications document that could be used by curriculum developers, educational policy researchers, publishers of curriculum materials, funding agency staff and school personnel both to inform the process and gauge the impact of current science curriculum reform efforts. It was clear from discussions and precis that the process of curriculum reform, like the educational process itself, is embedded within myriad cultures--those of the classroom, school community, government, and the larger society--and that a research agenda must necessarily include not only questions about the influence of policy, values, beliefs, and commitments at each level, but also questions about the interactions among these levels. This paper focusses on the report of that meeting, i.e., the nature of curriculum, the forces and factors that influence curriculum and reform, and recommendations for conducting research related to curriculum reform. Sections include: (1) "Executive Summary"; (2) "Participants"; (3) "The Need for a Research Agenda"; (4) "Understanding Curriculum Reform"; (5) "Exploring Research Issues"; and (6) "Recommendations." Recommendations are as follows: (1) long-term, comprehensive research projects must be initiated; (2) communication and collaboration must be valued; (3) teacher education must be transformed; and (4) new ways to report curriculum reform research must be explored. (55 notes) (KR)

ESTABLISHING A RESEARCH AGENDA:

THE CRITICAL ISSUES OF SCIENCE CURRICULUM REFORM

James A. Shymansky

William C. Kyle, Jr.

Report of a conference held April 8, 1990

Sponsored by
The National Association for Research in Science Teaching

Funded by
The National Science Foundation

The conference was sponsored by the National Association for Research in Science Teaching and supported by the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Association for Research in Science Teaching or the National Science Foundation.

Design and Production: John P. Campbell and Lois M. Campbell
Secretarial Assistance: Vickie Sanders
Artwork: Emilie Copeland

ESTABLISHING A RESEARCH AGENDA:

THE CRITICAL ISSUES OF SCIENCE CURRICULUM REFORM

James A. Shymansky

William C. Kyle, Jr.

Table of Contents

Executive Summary

On April 8, 1990, a group of science educators, researchers, sociologists, teachers, administrators, curriculum specialists, and policy makers convened to discuss the need to establish a research agenda focusing upon the critical issues of science curriculum reform. The meeting, held at the Atlanta Hilton and Towers, was sponsored by the National Association for Research in Science Teaching and funded by the National Science Foundation.

Research on science curriculum reform must become enculturated into the overall process of school restructuring and curricular reform.

The meeting was stimulated by the plethora of reports calling for the reform of science education. It is widely recognized that the schooling process is not empowering students with the reasoning, thinking, and problem solving skills requisite for full and critical participation in a global society. The emerging consensus is that science curriculum reform must be oriented clearly and effectively toward students' present and future human needs.

The meeting was premised on two assumptions: a) curriculum reform ought to be based on research, and b) curriculum reform ought to be evaluated by research. The meeting's objectives were:

* *to discuss the key research issues related to science curriculum reform, and*

* *to generate a research specifications document to both inform the process and gauge the impact of reform initiatives in science education.*

The meeting participants were chosen from a wide range of educational and research communities to ensure a broad base of discussion. Many of the participants had not met each other previously and few had collaborated professionally. Initially, several participants expressed reservations about how they might be able to contribute to the shared discourse regarding research and reform in the context of science education. Indeed, owing to their varied backgrounds, a unique dialogue transpired.

Each conference participant was asked to prepare a précis identifying critical issues or questions associated with science curriculum reform. The collection of précis were mailed to all participants prior to the meeting. It was apparent from the précis and the ensuing conference dialogue that the process of curriculum reform, like the process of education, is embedded within myriad cultures — each with its unique needs and concerns (e.g., the classroom, school, community, local and state government, and society-at-large). Thus, a research agenda must embrace questions about the influence of policy, values, beliefs, and commitments at each level. It must also address questions about the interactions among these levels. Moreover, research on science curriculum reform must become enculturated into the overall process of school restructuring and curricular reform.

The Atlanta Meeting was comprised of a series of large group and concurrent small group meetings. Ronald D. Anderson, Betsy J. Becker, Carolyn M. Evertson, and John R. Staver graciously agreed to serve as small group leaders. Following the Atlanta Meeting, each of the leaders prepared a report summarizing the group's activities, as well as the conference deliberations around four emergent themes that were introduced and revisited during the day's deliberations (e.g., policy perspectives and curriculum implementation, curriculum and instruction/teaching and learning, cultural factors influencing reform, evaluation and assessment, respectively).

We must engage in radical reform in science education. Reform must involve fundamental changes in course content, modes of instruction, teacher education, and student assessment.

The conference report:

* synthesizes discussions on the nature of the curriculum,
* identifies the forces and factors that influence educational and curricular reform, and
* recommends issues and questions to investigate related to curriculum reform in science education.

Each question raised by the participants, either in their précis or during the conference deliberations, is incorporated into this report. Questions raised by the conference participants appear in italics. We envision that this report will aid school personnel, curriculum developers, educational researchers, policy makers, publishers of curricular materials, funding agencies, and others in their quest to address the key issues of science curriculum reform.

In summary, we must engage in radical reform in science education. The participants agreed that, over the next decade, such reform must involve fundamental changes in course content, modes of instruction, teacher education, and student assessment. The restructuring of the process of schooling is necessary and timely. Contrary to popular opinion, however, educational reform can not be legislated. Moreover, science curriculum reform and research associated with the process of reform require synergistic interaction among curriculum developers, scientists, researchers, teachers, learners, community members, and school administrators. Each of these groups must be concerned participants in order for such cultural reform to occur.

Educational reform can not be legislated.

We are most grateful to the meeting participants. Each member came ready to share ideas and to deliberate the issues of primary concern to the fullest. We hope that this report is the first step toward achieving the broader goals of the science curriculum reform project.

James A. Shymansky
William C. Kyle, Jr.

Participants

Bill G. Aldridge
National Science Teachers Association

Hans O. Andersen
Indiana University

Charles W. Anderson
Michigan State University

Ronald D. Anderson
University of Colorado, Boulder

Betsy J. Becker
Michigan State University

Bonnie J. Brunkhorst
California State University, San Bernardino

Linda W. Crow
Baylor College of Medicine, Houston

Margaret Eisenhart
University of Colorado, Boulder

Carolyn M. Evertson
Peabody College, Vanderbilt University

Fred M. Finley
University of Minnesota

Fred Goldberg
California State University, San Diego

Raymond Hannapel
National Science Foundation

Larry V. Hedges
The University of Chicago

Jack Holbrook
University of Hong Kong

William G. Holliday
University of Maryland at College Park

Fred D. Johnson
Memphis Public Schools

Jane Butler Kahle
Miami University

Thomas R. Koballa, Jr.
University of Georgia

William C. Kyle, Jr.
Purdue University

Glenn Markle
University of Cincinnati

LaMoine Motz
Oakland Schools, Pontiac, Michigan

Joseph D. Novak
Cornell University

William F. Pinar
Louisiana State University

Charles Reno
Euclid Senior High School, Ohio

F. James Rutherford
American Association for the Advancement of Science

Thomas P. Sachse
California State Department of Education

James A. Shymansky
The University of Iowa

John R. Staver
Kansas State University

Myrtice Taylor
Atlanta Public Schools

Kenneth G. Tobin
Florida State University

Iris R. Weiss
Horizon Research, Inc.

Wayne W. Welch
University of Minnesota

Herbert E. Wylen
National Science Foundation

The Need for a Research Agenda

The purpose of this report is to synthesize the critical issues and questions associated with science curriculum reform for the purpose of establishing a research agenda. It is premised upon the belief that science curriculum reform ought to be *based on* research and *evaluated by* research. We aspire to inform the process and facilitate the assessment of reform initiatives. Ideally, a vision for improving science teaching and learning will emerge.

"Establishing a Research Agenda" marks the beginning of an intensive research project oriented toward sustainable reform in science education. The ultimate goal of this long-term project is to ensure that citizens develop the scientific and technological literacy for self- and social-empowerment.

Radical reform in science education is needed. A sound theoretical framework must underpin the systemic inquiry of science curriculum reform. We offer this report in the spirit of initiating such a dialogue. We neither claim to have raised all of the issues or questions imaginable, nor do we wish to restrict debate or inquiry. This report, then, is not a prescription for research. Rather, we hope to stimulate thought, reflection, and action on the nature, process, issues, and questions of science curriculum reform.

"Establishing a Research Agenda" marks the beginning of an intensive research project oriented toward sustainable reform in science education. The ultimate goal of this long-term project is to ensure that citizens develop the scientific and technological literacy for self- and social-empowerment. We encourage international communication, collaboration, and investigation on the critical issues and questions of science curriculum reform.

Science, Technology, and Cultural Needs

Science is a means for constructing and improving representations of the world. It should not be taken for granted that increased knowledge of the world would inevitably be useable. Nevertheless, it is apparent that new scientific insights have the potential to be readily and extensively applicable.[1]

Technology is the body of knowledge used in fashioning human invention, innovation, and the application of science. Technology is a source of cultural transformation. It is a social process achieving social ends, not an end in itself.[2]

Contemporary philosophers recognize that science is not just a self-subsistent intellectual activity, but a powerful force shaping us and the world. There is nothing politically neutral about these effects.

We can not isolate the scientific enterprise from the myriad other practices by which we define ourselves. Thus, any inquiry into modern science without centrally accounting for its technical capabilities would appear to be, if not bizarre, at least a little odd.[3]

Science and technology, then, have significantly influenced the course of history. Science and technology both shape and reflect our cultural values, as well as our environment. Our daily patterns of life and communication, our aspirations and our fears, how we see and judge perceptual thresholds, and the goals we aim for have been profoundly affected. Since science and technology are impinging more and more upon our day-to-day living, assuring literacy in these areas for today's youth must be a priority of educational reform.

Since science and technology are impinging more and more upon our day-to-day living, assuring literacy in these areas for today's youth must be a priority of educational reform.

Our world has been substantially reconstructed in a very short period of time. Much of this transformation has been stimulated by a tremendous increase in knowledge discovery and dissemination, in concert with an appreciable decrease in the span between knowledge construction and application. In addition, technical innovations and commonplace uses of technology have contributed to a greater sense of global interdependence.

The broader cultural significance of science, however, has been given little attention. This should surprise science educators, especially in light of the universalism generally ascribed to scientific knowledge and practice.

> *Why has the broader cultural significance of science virtually been ignored?*

The totality of socially transmitted behavior patterns resulting from advancements in science — the culture of science — is difficult to define in a world composed of political, demographic, socio-cultural, and economic diversity. Scientific knowledge and practices have not equally benefitted developing and developed nations. In fact, in developed nations with a multiplicity of cultures, the dominant culture has benefitted disproportionately. It should be apparent, then, that scientific knowledge and practices are not extended beyond the laboratory by generalization to universal laws. Rather, scientific knowledge and practices are extended by adaptation of locally situated practices to new local contexts. Thus, scientific knowledge and practices must be interpreted within specific social contexts.

Scientific knowledge and practices must be interpreted within specific social contexts.

A reformed science curriculum ought to afford learners the opportunity to investigate the practical, social, contextual, and political dimensions of science. The following questions might guide such inquiry:

A reformed science curriculum ought to afford learners the opportunity to investigate the practical, social, contextual, and political dimensions of science.

How have the natural sciences changed us?

How can we understand and assess these changes?

What is the social and political impact of the extensive application of scientific insights?

How and why have the growth and development of the sciences contributed to the vast expansion of the technological power at the disposal primarily of the Western nations and their institutions?

How can science assist developing countries in ways accessible to their resources, in harmony with indigenous technologies, and/or appropriate to their traditions?[4]

One of the most compelling truths of living is the process of change. We have entered an exciting era — a time when change will be as unpredictable as it is inevitable. We are on the brink of a new world order. The East-West ideological conflict that dominated international affairs for more than a generation is over. A new agenda must emerge to guide world affairs for the decades to come. It has been suggested that the battle to save the planet ought to replace the battle over ideology as the organizing theme. If efforts to reverse environmental degradation dominate world affairs, then environmental sustainability will become the new order. This agenda would be more ecological than ideological, more global than national, more cooperative than competitive, and more farsighted than shortsighted.[5] Regardless of the ultimate theme and agenda, an understanding of the practical, social, and political dimensions of science will enable the scientifically literate citizen to participate in the framing of a new social order.

The reform of science education must address the needs of science, technology, and culture. The reform of schools and teacher education must be in harmony. A conception of our image of reform must be grounded in answers to the following questions:

What will students need to know to be scientifically literate?

What will teachers need to know to be able to redesign their schools?

What are the values, images, customs, beliefs, and practices associated with the teaching and learning of a reformed science curriculum?

In addition, a science education oriented toward self- and social-empowerment ought to be concerned with the following issues:

School science ought to ensure that all students construct the same outcomes for interpreting the world in a self-adjudicatingly social way. Presently, students are offered different types of knowledge by means of ability grouping and tracking. This leads to unequal learning opportunities and the creation of a scientific elite.

How can the nature of science be used to inform instruction? By highlighting the contextual nature of science, *Will students be better able to mediate their culture and everyday views with formal science instruction?* And, if so — *Will students become informed enough to make and affect "real world" scientific decisions as a result of their science instruction?*

What are the community values and beliefs regarding science? How do the cultural milieu, linguistic conventions, social contexts and activities differ from formal science? How might translations among them be achieved?

School science ought to ensure that all students construct the same outcomes for interpreting the world in a self-adjudicatingly social way. Presently, students are offered different types of knowledge by means of ability grouping and tracking. This leads to unequal learning opportunities and the creation of a scientific elite. Disenfranchised students are effectively prohibited from participating in the practical, social, and political dimensions of science. Their access to higher levels of formal science and/or entry into science- and technology-oriented careers is severely restricted.

Scientific literacy for all should start to mean just that — literacy for all — not just literacy for the subset of youth who happen to be born into the dominant-group ideology.[6] In our efforts to reform science education and to engage in research related to reform, we must be mindful that, "all experience and knowledge are relative to various contexts, whether physical, historical, cultural, or linguistic, and that as the contexts change, so do the perspectives one has."[7] We must use our contextualized experience and knowledge to guide ethical improvements in science education.

Schooling Needs

Ironically, modern science and technology have transformed the world in which we live more so than how we think about the world. There is no other segment of our culture that lags behind "everyday society" as much as the process of schooling. A nineteenth century youth would feel much more comfortable in our schools than in our homes, industries, businesses, or cities.[8] Moreover, while schools lag behind everyday society, they often perpetuate the production of knowledge in the context of social, economic, and political ideologies of the dominant culture.[9]

Changes in society, science, and technology necessitate that we question the purposes and traditions of schooling. We need to reexamine the moral choice put before us as educators and citizens, a choice that John Dewey suggested is the distinction between "education as a function of society" and "society as a function of education." In the process of reexamining that choice, we need to ask:

> Should schools serve and reproduce the existing society or challenge the social order so as to develop and advance its democratic responsibility?
>
> Do we desire schools to create a passive, risk-free citizenry, or a politicized citizenry capable of assuming social responsibility, informed by a concern for equality, social justice, and civic rigor?[10]

There is no other segment of our culture that lags behind "everyday society" as much as the process of schooling. A nineteenth century youth would feel much more comfortable in our schools than in our homes, industries, businesses, or cities.

If the ultimate goal of this reform project is to ensure that students develop the scientific and technological literacy for self- and social-empowerment, then the answer to each of the above questions should be indisputable. Curriculum reform must address this issue. Research must purposefully assess whether students have acquired the knowledge and skills associated with citizenship and social responsibility.

The purpose of school is not merely to help students achieve academically, but to prepare students to lead fulfilling lives. The true manifestation of successful schooling is not how well students perform on in-school assessments. How citizens think, what they value, how analytical and critical they can be, how they question and reflect — these are among the true measures of successful schooling. The most valid measures of the effectiveness of today's school science experiences might not be available for twenty years. For example, "How creative, imaginative, and resourceful will citizens be in resolving science - and technology-oriented community-based issues that are unimaginable today?" Admittedly, information regarding the effectiveness of reform initiatives will be desired in the interim. We encourage evaluators, however, to utilize a broader vision of assessment than has traditionally accompanied curriculum reform efforts. Rather than focusing upon the narrow and shortsighted priorities of education, assessment should begin to focus upon issues that really count.

We encourage evaluators to utilize a broader vision of assessment than has traditionally accompanied curriculum reform efforts. Rather than focusing upon the narrow and shortsighted priorities of education, assessment should begin to focus upon issues that really count.

While it is inevitable that the social milieu, the science, and the technology of the 21st century will be vastly different from what they are today, the challenge confronting science educators worldwide is,

> *How do we prepare all of today's youth for tomorrow's society?*

We must begin to create a vision of hope, a vision that enables youth to fulfill their dreams, rather than settle for the tarnish of reality.

Schooling can no longer function in isolation from the realities of present-day living. Schooling must begin to transpire in the context of the public spheres and lived experiences of learners. The traditions of school practice, dating back several centuries, must be questioned. Evidence is mounting that the archaic ritual of "transmission and acquisition of knowledge" is not able to provide students with the science and technology education requisite for future human needs. A consensus has been reached that science learning is more than information absorption; students must be actively engaged in the process of learning so that they can apply their observations, knowledge, and interpretations to the world around them. The process of learning and teaching, then, must reflect the dynamic, open-ended, aesthetic, and investigative dimensions of science.

The key issue among science educators is not, "Should science education be reformed?" Rather, the issue is,

What ought a reformed science education offer learners and society?

Similarly, the debate is not whether fundamental concepts should be taught or whether process skills are essential. The focus is upon,

Which fundamental concepts ought to be integrated into the curriculum?

What does it mean for a student to understand something scientifically?

How should science be taught and assessed?

What skills should students acquire to facilitate their ability to function in society?

How can science education help students interpret their everyday science experiences?

Science Education Needs

"The only thing new in the world is the history you don't know."[13]
Harry S. Truman

Addressing the critical issues of science curriculum reform for the purpose of establishing a research agenda necessitates an understanding of the history of science education. Our history reveals the social, cultural, political, and economic conditions under which science education goals have been formulated and subsequently changed.[11] Our history offers insight and perspective to such questions as:

Why does science education change?

How does science education change?

What changes in science education?

When does science education change?[12]

Presently, there exists widespread international recognition of the need to reform science education. The euphoric notion of "getting on with reform" is inspired by the desire to prepare citizens for the 21st century, yet tempered by the recognition that the reform efforts of the 1960s failed to result in any lasting change. The educational achievements of the 1960s clearly indicate that localized, short-term improvements are possible.[14] At the very least, this informs us that change can occur and that reform is worth pursuing. More importantly, it informs us that: a) true reform is much more difficult to achieve than was thought previously; b) the process of schooling is affected by social and political realities; and c) quick fixes to curriculum reform are doomed to failure.

In the context of the emerging curriculum reform era, the science education community must recognize, debate, and investigate such critical issues as:

How does science education respond to the societal demands of schooling?

Over a century ago, Herbert Spencer reminded educators that one of the fundamental questions of schooling is, "What knowledge is of most worth?"[15] Historically, conflicts have persisted over what should be taught. This issue is as much an ideological and political one as it is an educational one. Educational and curricular issues have always been enmeshed in the history of class, race, gender, and religious relations.[16]

A contemporary way of phrasing Spencer's question — to highlight the profoundly political nature of the educational debate — is, "*Whose* knowledge is of most worth?"[17] Science educators have largely ignored or failed to recognize the importance of this issue. For example, how we respond to two distinct societal demands that predominate the reform literature will, to some extent, determine whose knowledge ought to be taught. That is,

Should science education ensure a scientifically- and technologically-oriented work force versus ensure scientific and technological literacy for all?

Traditionally, the offering of different knowledge — tracking to accommodate the perceived needs of science-bound students — has created unequal structures with unequal outcomes. The differentiated structure of schools throws up barriers to achievement and participation in science and technology. The victims of such disenfranchisement have generally been members of minority groups, women, and poor students.[18]

The offering of different knowledge — tracking to accommodate the perceived needs of science-bound students — has created unequal structures with unequal outcomes.

Teachers — and others concerned with curriculum decision making — must begin to engage in serious discourse regarding the ideology, content, and values that will become the hallmark of the emerging curriculum reform era. Debate regarding science curriculum reform should focus upon:

What (whose knowledge) counts as a legitimate science education?

What should students know and be able to do?

How should that knowledge be organized for purposes of instruction?

Answers to the above questions will influence many other decisions. It is virtually impossible to consider how instruction should occur and what should be assessed prior to deliberating the nature of the curriculum. In essence, "No matter how well something is taught, if it is not worth teaching, it's not worth teaching well."[19]

The present reform should not perpetuate the class, race, and gender inequities of the past.

Since the present reform agenda challenges many of the traditional values of schooling and teacher education, we urge you, the prospective contributor to reform research, to imbed the perspective of history within your inquiry. Your discussion of present issues and the concomitant extrapolation of such issues to the future will be enriched by history. We also urge you to seriously address the issue of *whose* knowledge is of most worth. We ask that you rationalize your response to this critical issue with each and every curricular decision that you make or investigate. The present reform should not perpetuate the class, race, and gender inequities of the past. The successful reform of science education ought to contribute to an emerging culture of science.

Research in Science Education Needs

Science education has a long and important history. As a field of scholarly endeavor, however, science education is relatively young. Early research studies of importance were often conducted by educational psychologists. Throughout the first half of the 20th century, most psycho-educational inquiry focused on issues or topics that largely excluded subject matter. Educational psychologists merely expected significant findings to be applied in the context of teaching and learning in each of the disciplines. During this period, most science educators focused their efforts on teacher education. Their writing was typically restricted to textbooks and instructional materials.

When science educators did engage in research, their inquiry was often premised on a concern for more effective science teaching. Effectiveness was measured in terms of increased student performance on predetermined variables of interest. The dominant research methodology was the agrarian statistical model; little distinction was made between investigating the effects of the amount of fertilizer per acre to maximize yields and profits vs. whether the kinds of questions that teachers ask influence students' understanding of science. Studies often lacked a theoretical rationale or framework. Seldom did science educators contribute to the generation of theory. These early, small-scale investigations were conducted in isolation, with limited resources, and without the benefit of collaborative inquiry or collegial critique.

Beyond the wildest dreams of most science educators, their role and image changed almost overnight with the passage of the National Science Foundation Act (NSF) of 1950. The NSF-funded curriculum development projects of the late 1950s through the early 1970s ushered in numerous research opportunities. Despite massive government funds for curriculum development and implementation, minimal research was conducted. Many critical research questions were never asked. Almost all research on curriculum reform was conducted by individual investigators — often as dissertations. Adherence to the adopted agricultural research methodologies persisted. The research initiatives could be characterized as: small-scale, one-shot investigations, without subsequent follow-up.

Today, the science education research community generates nearly 500 manuscripts per year. Researchers embrace the full range of methodologies — qualitative[20] and quantitative — to address both basic and applied questions. While several research themes have emerged over the past decade as a result of interdisciplinary work,[21] most investigators focus their inquiry on topics within such diverse areas as: the nature of learning; the process of teaching; learner and/or teacher characteristics; the assessment of students, teachers, curriculum, or instruction; and teacher education.

The landscape of primary research is punctuated each year by a few research syntheses or summaries. Occasionally, studies complement or build on one another enabling the emergence of a new perspective with the potential for far-reaching implications (e.g., the growing consensus about the nature of the learner). More often than not, though, published studies fail to impact the community of researchers, practitioners, teacher educators, or policy analysts/decision-makers. Researchers often express frustration at the lack of substantive impact of their efforts.

Attention must be paid to the wider socio-cultural, economic, and political contexts in which schools function.

Why does so much effort result in such little apparent benefit?

First, most research in science education bears little relevance to the context of the lived experiences of teachers and students. Researchers have paid little attention to the historical, cultural, social, economic, and political aspects of schooling. It should not be surprising, then, when isolated instances of significant differences in highly controlled "laboratory environments" are not translated into practice. More research, in and of itself, is not needed to improve the condition of science education. Rather, attention must be paid to the wider socio-cultural, economic, and political contexts in which schools function. Second, historically, it has been difficult for researchers to engage in substantive educational reform. Most science education research produces knowledge in the context of a system clinging to tradition.[22] The production of knowledge in such a context perpetuates the social, economic, and political ideologies of the dominant culture and fails to contribute to a vision of social transformation.[23]

Can research in science education contribute to the process of reform and social transformation, thereby enhancing science teaching and learning? In our view, research in science education is a central component of achieving sustainable reform. The NSTA Theme Paper on *The Role of Research in Science Teaching* declares that "research should guide and inform policy formation and decision-making regarding science teaching" and recommends that "a more reasoned and reasonable approach to curricular, instructional, and evaluative decisions must be undertaken."[24] Thus, there is a critical need for the science education community — researchers, practitioners, policy makers — to construct a comprehensive image of the purposes to be served by reform. This image must be intellectually honest and pedagogically valid.

A Formidable Challenge

Science education research has come a long way over the past twenty-five years. It has not yet gained the credibility to make a difference in practice, though. Researchers must attend to the critical issues associated with the process of educational reform in general, and science curriculum reform in particular. The science education community must acknowledge that the reform of research in science education is as imperative as science curriculum reform.

We stated earlier that a sound theoretical framework must underpin the systemic inquiry of science curriculum reform. The issues and questions that have been raised in this section are an essential component of such a framework. Science educators must respond to a formidable challenge:

> *Can we find a collective voice that speaks to the issues of sustainable reform?*

BEST COPY AVAILABLE

Understanding Curriculum Reform

A majority of the world's countries have experienced reforms or revisions of their science curricula since the 1960s. The influence of these efforts has varied. Frequently, success has been less than what was desired. Presently, there is renewed interest and willingness to improve science education.[25]

Today's priority must be to stimulate creative thought about tomorrow's science curriculum.

The international quest to reform science education is inspired by:

* a new view of curriculum,
* an emerging consensus regarding the nature of the learner and the process of teaching, and
* a new image of the role of the teacher.

Reform...Reform...Reform!

Today's priority must be to stimulate creative thought about tomorrow's science curriculum. Even if the reforms of the past had accomplished all of their goals, curriculum renewal would be necessary to address current issues and concerns. The critical issues and questions of science curriculum reform must be debated in the context of an adequate understanding of the cutting-edge developments in research on teaching and learning.

Reforming science education will be a difficult and lengthy process. It must involve all parties interested in improving schools — e.g., teachers, learners, administrators, researchers, curriculum developers, test developers, state and local boards of education, parents and community members, policy makers, professional organizations, and the colleges and universities that prepare future teachers.

How can reform occur when there appears to be such inertia in the system at all levels?

We contend that the apparent inertia is, in part, a product of the "reform initiatives" that have been imposed upon schools by policy makers and legislatures. The ever-changing, quick-fix, technical approach to resolving the non-technical issues of schooling fosters confusion and inaction. The prevailing focus on achievement, assessment, and accountability has neither identified the problems of schooling, nor offered solutions that are pedagogically valid.

Different stakeholders will always possess varying notions regarding the nature and severity of current problems and how to best resolve them. Ideally, enhanced communication among the stakeholders will lead to negotiation and consensual agreement on the issues to be resolved and the action to be undertaken. All stakeholders should be concerned by the fact that reforms seldom substantially alter the regularities of schooling.

The prevailing focus on achievement, assessment, and accountability has neither identified the problems of schooling, nor offered solutions that are pedagogically valid.

Why do so few reforms aimed at the classroom make it past the door permanently?

What have we learned from research associated with past curriculum reform efforts?

We wish to respond to these questions by offering four principles.[26] First, ***the process of curriculum reform should be investigated.*** The literature does not reflect the richness of past experiences. In particular, knowledge of the experiences of teachers and others most closely associated with the process of reform is almost non-existent. The following questions are asked frequently:

Are there important processes and factors related to the implementation and institutionalization of reform initiatives?

What are the encouragements, constraints, ideas, and outcomes that might apply to new reform initiatives?

Are there essential attributes of systemic reform? What is the nature of the support system that is necessary for sustaining reform? What is necessary to ensure that the kinds of commitments requisite for success are forthcoming?

Are there common impediments and constraints to change? If so, what are possible solutions to such impediments and constraints?

What strategies promote collegiality among teachers, administrators, researchers, science educators, scientists, and others interested in curriculum reform? What factors isolate and prevent teachers from working collegially and how can these be overcome?

What is the role of staff development in the process of reform?

What is the correlation between the idealized curriculum and the taught curriculum?

These are all questions that impact upon the process of reform. Unfortunately, information regarding the process of change is seldom reported. The literature reveals a critical need for enhanced communication and collaboration among reform participants and researchers. Participants in reform projects must become, and see themselves becoming, actively involved in the planning, acting, observing, and reflecting stages of curriculum reform. Inquiry regarding the process of curriculum reform should be aimed toward improving local educational situations, yet reported in the literature to facilitate reform in other locales.

Participants in reform projects must become, and see themselves becoming, actively involved in the planning, acting, observing, and reflecting stages of curriculum reform.

Second, ***research should be for educational reform, not about educational reform; it should unify — not separate — the work of educational theorizing and practice.*** In this sense, the process of reform should be collaborative and participatory. The collaborative action research model brings together teachers, researchers, staff developers, and others interested in the reform process for the purpose of improving practice. Its goal is to empower teachers to become self-reflective researchers, that is, practitioners who can examine their own practice critically. Through the process of investigating and reflecting, teachers become more flexible in their thinking, more receptive to new ideas, and more adept at converting a problematic situation into a problem to be resolved. Collaborative action research also enables teachers to clarify, modify, and elaborate the theories that inform their instruction. Thus, it offers a method for testing and improving educational practices.

Third, ***research should contribute to improving curriculum, instruction, and assessment.*** In order for improvement to occur, teachers must be actively involved in the planning, acting, observing, and reflecting stages of reform research. After all, improved practice is not the end, improved understanding of each phase of the reform project and how it contributes to transforming schools and classrooms is desired. Previously, researchers focused almost exclusively upon quantifying the outcome of instructional innovations, such as: discovery learning, mastery learning, cooperative learning, the use of extended thought questions, or wait-time. "Amid the eagerness to improve instruction, too little attention has been paid to deciding which subject matter the improved instruction should help students achieve. This is folly. The best teaching methods cannot possibly overcome a weak curriculum. Brilliant instruction about irrelevant content should not impress anyone."[27] Research should focus on the entire process of curriculum reform. Our understanding of science teaching and learning will be enhanced by practitioners and researchers theorizing, planning, conducting, and interpreting research that is pedagogically relevant.

Our understanding of science teaching and learning will be enhanced by practitioners and researchers theorizing, planning, conducting, and interpreting research that is pedagogically relevant.

Fourth, ***science curriculum reform and curriculum reform research should transform schools and classrooms.*** There is evidence to suggest that reforms recur because they are never intended to do just that — transform schools and classrooms. Reforms rarely get adopted as policy. Most get implemented in word, rather than deed. Often only the symbols of reform appear in classrooms: new tests, different rules, revised curriculum guides, and new equipment or computers. "Seldom are the deepest structures of schooling that are embedded in the school's use of time and space, teaching practices, and classroom routines fundamentally altered even at those historical moments when reforms seek those alterations as the goal."[28]

In our zeal to reform, we must be mindful that the purpose of reform is to take action upon concerns or problems. Thus, we must start with the problem, not the innovation. There should be a connection between the problem and the context in which we will attend to the situation. We must adopt the long-term rather than quick-fix approach to curriculum reform. We must be more interested in problem setting and resolution, reflection and action, and communication and collaboration vs. innovation for the sake of innovation, technical cures for non-technical dilemmas, and individual one-shot investigations.

Science curriculum reform and research associated with the process of reform require synergistic interaction among each of the stakeholders. These groups must be concerned participants in order for such cultural reform to occur. Further, such reform will not occur unless those involved in the process "own it." If reform means transforming schools and classrooms, then it must be guided by an understanding of the process of change and a vision of the future.

The Process of Reform

Ironically, perhaps the most enigmatic expression of the 1980s was "curriculum reform." The rhetoric associated with the call for reform disregarded many fundamental questions, for example:

> *What is curriculum reform? When, where, and how does reform begin? What factors influence a willingness to engage in reform? What are the roles and responsibilities of each of the stakeholders associated with the reform process?*
>
> *How are reform initiatives enculturated into the process of schooling? What are the impediments to reform, as well as the constraints upon the implementation of a reformed curriculum? What constitutes reasonable measures of successful curriculum reform? Is there a shared consensus regarding the attributes of "success" among the various stakeholders?*

The above questions should be deliberated throughout the reform process, that is, in the context of the development, implementation, and assessment of science curriculum reform initiatives.

Teachers will need to construct collegial ties within and beyond the school, as well as assume leadership roles associated with the process of reform and professional renewal.

Change in schools requires leadership, staff development, changes in the organizational structure, and the involvement of people from all aspects of the educational system. These components must work in concert and be adapted and revised throughout the various phases of implementation.[29] Throughout the process of reform, teachers will need to construct collegial ties within and beyond the school, as well as assume leadership roles associated with the process of reform and professional renewal.

Since the purpose of reform is to change the present curriculum, prior questions must also be addressed, such as:

> *What is happening in the present science curriculum and why is it happening?*
>
> *What change is desired and why?*
>
> *What is the research base upon which major reform initiatives are premised?*

These questions are often ignored in the literature. There is little evidence to indicate that they are not similarly ignored in the process of reform! *How can research on curriculum reform proceed if there is no stated rationale for the reform? Is the reform process and the research on reform really transpiring against a backdrop of non-existent knowledge? Are schools and teachers really being asked to change without any knowledge of what presently occurs in classrooms? Could conclusions and interpretations from such studies be warranted?* Adequate reference to the present status and desired state will comprise a grounded theory, the viability of which can be investigated and elaborated upon in a wide range of contexts.

We have viewed a curriculum in terms of the culture in which it is embedded. A curriculum consists of the practices, customs, beliefs, metaphors, and values of teachers, students, administrators and others who are directly or indirectly involved in science education.

The process of curriculum reform is dynamic and often occurs in stages, over long periods of time. The questions above should be systematically addressed in the initial stages of reform. These issues should be monitored throughout the reform process. The information gathered and lessons learned early in the project should guide decision making in later stages. If initial plans are modified to address encouragements or constraints, then the modes of resolution should be described thoroughly. Lessons learned in the reform process ought to be used both to modify the present reform process and facilitate future reform efforts in other locations.

Rethinking Curriculum Research and Practice

What is science curriculum? We have viewed a curriculum in terms of the culture in which it is embedded. Thus, a curriculum consists of the practices, customs, beliefs, metaphors, and values of teachers, students, administrators, and others who are directly or indirectly involved in science education. This culturally orientated perspective on science curriculum invites new questions and alludes to many of the problems that have faced educators in the past.

What are the values, images, customs, and practices associated with traditional approaches to the teaching and learning of science?

What are the prevailing personal epistemologies of teachers and students and how do these compare with the epistemologies embedded in routine practices?

What factors influence the selection of content and the activities used to promote learning of science?

Research ought to have the potential to influence practice.

If the quality of science education programs is to be improved, then it is essential that the tried and tested approaches to research and practice be queried. With respect to practice, it is necessary to understand the processes involved in teacher change and school change. And with respect to research methodology, it is essential that simplistic program comparisons be replaced by interpretive inquiry or action research. It is not just a case of complementing quantitative with qualitative data, of using a mix of qualitative and quantitative methodologies, or of doing qualitative inquiry as a prelude to "more representative" quantitative studies. We need to be asking and answering questions that are not amenable to traditional research methods. An interpretive or critical approach incorporating a constructivist epistemology will enable different questions to be addressed and different solutions to be obtained. It is anticipated that the answers to such questions will be more readily assessable to teachers and others involved in science curriculum reform. Thus, the research ought to have the potential to influence practice.

Two theoretical frameworks appeal as being suitable for research on science curriculum. The first is "radical constructivism."[30] The second is the theory of "knowledge constitutive interests."[31]

Radical Constructivism. Analyses of teachers' thoughts and practices can be based on images, metaphors, beliefs and values considered from a constructivist perspective. There is evidence to suggest that metaphors and imagery influence how teachers think and talk about teaching and what they do in the classroom.[32] When teachers act in the classroom they do what makes sense to them given the circumstances. What has worked in the past and seems likely to be effective in a given context are criteria that guide a teacher's selection of appropriate practices. Decision-making usually is not conscious and certainly is not focused on each of the myriad behaviors that comprise the various roles to be adopted in any lesson.

Epistemological theories which have had a strong influence on how teachers guide learning in their classrooms have been historically based on an empiricist philosophy, an idea that knowledge is "out there" in the world and has only to be accessed by the senses in order to be transferred to the learner. According to this philosophy, one needs to be objective in order to match observations with an external and accessible reality. Traditional teaching and learning strategies in science have developed from objectivist assumptions about knowledge and incorporate a conduit metaphor whereby knowledge is piped from the teacher to students. Concern is directed towards the pursuit of learning truths about the universe in which we live.

Interpreting the data on classroom practices in the light of a constructivist view of learning leads us to assert that teachers make sense of their roles in the teaching-learning process by constructing pedagogical knowledge that "fits" the context of the classroom environment.

Learning strategies based on a constructivist epistemology acknowledge the subjectivity of observation. What we see is an interpretation of our experiences based on what we know. Knowledge is not regarded as being out there. On the contrary, knowledge is found in the minds and bodies of cognizant beings.[33] Within a constructivist framework, learning is defined as the construction of knowledge by individuals as sensory data are given meaning in terms of prior knowledge. Learning is an interpretive process which involves constructions of individuals and social collaboration.

Interpreting the data on classroom practices in the light of a constructivist view of learning leads us to assert that teachers make sense of their roles in the teaching-learning process by constructing pedagogical knowledge that "fits" the context of the classroom environment. However, teachers believe they are constrained to implement the curriculum in a traditional manner. Through interactions with peers and students they construct beliefs about the nature of knowledge, how students learn, and what strategies may best be applied in a given teaching-learning environment. Since teachers believe constraints to be "true" it is not surprising they allow their beliefs to influence their classroom practices. Consequently, even when changes in classroom practices are desired, certain beliefs held by teachers (i.e., constraints) act to prevent the changes being put into effect. Additional questions of interest, then, are:

> *What changes in the science curriculum as a teacher's personal epistemology changes from realism to constructivism?*
>
> *What changes occur (i.e., in the images, metaphors, beliefs, customs, practices, and perceived constraints) when teachers endeavor to implement a constructivist curriculum?*

Knowledge Constitutive Interests. Habermas identified three basic cognitive interests: technical, practical, and emancipatory. Persons guided by technical interests have a basic orientation towards controlling and managing the environment. Control is achieved through rule-following actions based upon empirically grounded laws. A primary concern is with the product or outcome of the curriculum. In the school context, technicists identify these laws as legislated mandates, curriculum guides, and/or standardized tests. Realism is the epistemology that most often underlies technical interests and the metaphor associated with schools that emphasize technical interests is "school as work place." In contrast, practical interests have a basic orientation in the form of interpretive understanding, which can inform and guide judgement. Negotiation and consensus making are important components of practical interests. A curriculum with an emphasis on practical interests is often based on constructivism and emphasizes learning with understanding. The metaphor that pervades schools in which practical interests predominate is the "school as learning place." Emancipatory interests lie in empowerment, which allows individuals or groups to engage in autonomous action that emphasize reflection and deliberative actions. Teachers and students are empowered to take control of their practices and thoughts in autonomous and responsible ways. The knowledge and science represented by each of these interests can be represented in the following way:

Interest	Knowledge	Science
Technical	Instrumental (causal explanation)	Empirical-analytic or natural sciences
Practical	Practical (understanding)	Hermeneutic or 'interpretive' sciences
Emancipatory	Emancipatory (reflection)	Critical sciences

Standard Setting vs. Standardized

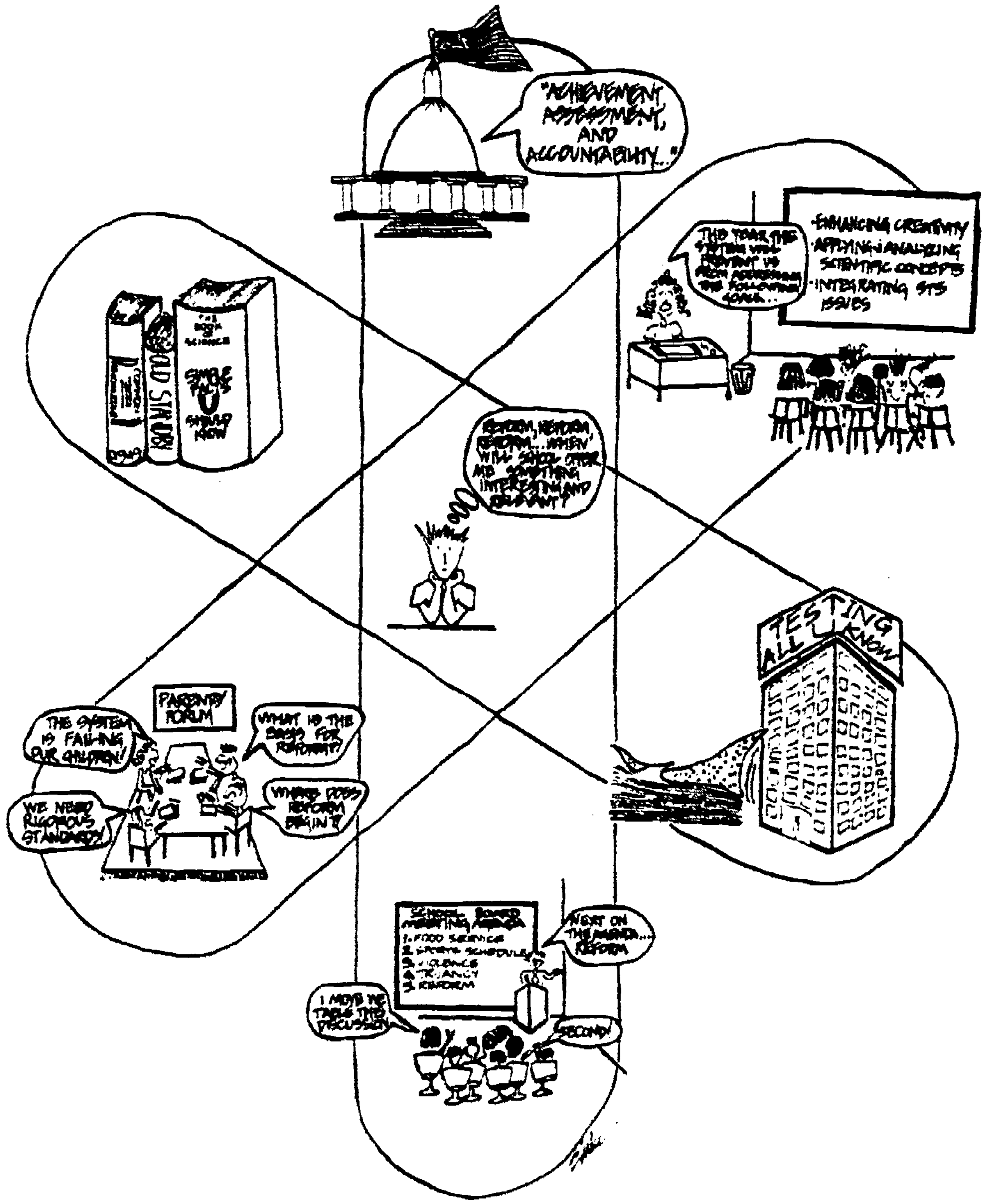
In the context of establishing a research agenda, we previously emphasized that science curriculum reform is necessary to ensure that all students develop the scientific and technological literacy for self- and social-empowerment. Further, we urged science educators to find a collective voice oriented toward the issues of sustainable reform.

Science educators, in collaboration with teachers, must begin to exert a controlling influence over the pedagogy that should be transpiring in schools. Students should not have to wonder when school will offer something interesting, relevant, and challenging.

The standards presently espoused by textbook publishers, test developers, and policy makers contrast sharply with: a) current insights regarding the process of teaching and learning; b) the recognized failure of norm-referenced tests to measure student understandings, interpretations, higher-order thinking skills, and use of science process skills; and c) the realization that teachers must be actively involved in shaping the purposes and conditions of schooling. This disparity is attributable to the failure of science educators and teachers to claim a voice in the reform process. Science educators, in collaboration with teachers, must begin to exert a controlling influence over the pedagogy that should be transpiring in schools. Students should not have to wonder when school will offer something interesting, relevant, and challenging. The process of reform must ensure that important knowledge is sequenced appropriately and that each student is engaged in meaningful learning every day. Science curriculum reform should be standard setting, not standardized.

The rationale advocated herein for reforming science education and investigating the critical issues of science curriculum reform contrasts with popular notions in the United States. These notions emerged with the publication of *A Nation at Risk* and have influenced dozens of education reports since 1983.[34] The reform discourse has been shrouded in an ideology preoccupied with international competitiveness, national security, the preservation of an ethnocentrized cultural polemic, the deprofessionalization and deskilling of teachers via the adoption of "teacher-proof" curricula, and the imposition of standardized testing.[35] Rather than offering a vision of empowerment, this ideology serves to disenfranchise and alienate both learners and teachers.

Policy makers and legislatures have become obsessed with having students in the United States achieve first on international assessments of science and mathematics.[36] This goal was initially established by the National Science Board with a target date of 1995.[37]



Science educators, in collaboration with teachers, must begin to exert a controlling influence over the pedagogy that should be transpiring in schools.

Following the 1989 Education Summit, it was reaffirmed among the six National Education Goals proclaimed for achievement by the year 2000:

> **"By the year 2000, U.S. students will be first in the world in science and mathematics achievement."**
>
> **National Education Goal #4**

From a technical point of view, Colorado's Governor Roy Romer, chair of a National Governors' Association goals panel, acknowledges that: "Some of these goals certainly are grandiose....The math and science goal in particular is probably unreachable."[31] We wish to question any nation's preoccupation with such a goal from a pedagogical point of view:

Why should students be "number one" on standardized assessments that measure recall of narrowly-defined facts and insignificant value-free content?

What is the rationale for such a shallow perspective to the enormous task of curriculum reform?

Pressure to standardize curriculum, instruction, and assessment blatantly disregards the contextual reality that was stressed previously (while rationalizing a research agenda from four perspectives: science, technology, and cultural needs; schooling needs; science education needs; and research in science education needs). Standardization:

* limits the ability of teachers to engage in discussion surrounding the notion of "what" and "whose" knowledge is of most worth;

* controls what is taught and perpetuates the production of "teacher-proof" curricula, which bypass and insult teachers' intellectual and decision-making capabilities;

* ensures an overemphasis on reading comprehension, vocabulary acquisition, and the memorization of isolated facts; concomitantly, there is a de-emphasis on doing science;

* precludes the teachers need to focus on students' prior knowledge of science, since the focus of instruction is superficial coverage versus meaningful understanding;

* ensures that students do not come away from instruction with a rich and useful understanding of science concepts;

* ensures that students are not afforded the opportunity to investigate the practical, social, contextual, and political dimensions of science; and

* perpetuates the disenfranchisement of minorities, women, and poor students, as well as their underrepresentation in science- and technology-oriented careers.

Poor instruction can be rationalized by policies that advocate the decontextualized pursuit, capture, and regurgitation of trivia. In fact, there is little need to alter the curriculum or instruction when the benchmark of "reform" is how well students score on standardized tests! This perspective to education views knowledge as an act of transference and views good learners as those willing to spew back the information intact without any critical thought, action, or reflection. Paulo Freire refers to this narrow image of literacy as "banking education." That is, learners are viewed as empty vessels into which technicians deposit the right knowledge.[39]

Schools must enhance the ability of all students to become active learners, capable of learning how to learn.

A Re-formed Curriculum

If we desire citizens who are creative, reflective, critical thinkers, and problem solvers, then schools must enhance the ability of all students to become active learners, capable of learning how to learn. In a re-formed curriculum, teachers, parents, and others concerned with the education of our youth would be empowered to transform the lived experiences of the classroom, thereby affording students the opportunity to develop the modes of thinking to fully and critically participate in a democratic community. In a re-formed curriculum, teachers would be afforded the time to share ideas with colleagues, participate in professional development, and engage in inquiry about teaching and learning. Teachers would be active, reflective practitioners engaged in constructing a curriculum. In a re-formed curriculum, researchers would collaborate with practitioners to inform the process and influence practice.

> Substantive and continuing educational improvement will be difficult to achieve unless teachers begin to play a greater role in identifying the key impediments to progress in education and in figuring out how to do something about them. The progress of meaningful school reform will be stalled until teachers emerge from their marginal positions in the research community and become full partners in the conception and the conduct of educational inquiry.[40]

Science for All Americans accurately portrays the curricula in science, noting it is overstuffed and undernourished.[41] The "information age" has made it increasingly difficult for teachers and students to identify the science, mathematics, and technology that is truly essential. Ironically, this is good news! We must finally confront the knowledge explosion and recognize that the curriculum can not grow without restraint. Schools can no longer be asked to teach more and more, but ***must be asked to teach less*** so that it can be taught better. Equally as important, the rigid boundaries between the disciplines must begin to crumble so that students can experience the connections among disciplines. "We now seem ready for a new round of curriculum reform. This time the stimulus need not be the apparent want to compete with a state that has launched a new era of space exploration, but a recognition that all countries must cooperate to ensure that we educate a scientifically and technologically literate citizenry."[42]

Reform must be standard setting, it must involve teachers in the process of advancing new research policies and practices, and it must ensure that all students are the benefactors of a re-formed curriculum.

Curriculum, instruction, assessment, and research in science education must be re-formed. The reform must be standard setting, it must involve teachers in the process of advancing new research policies and practices, and it must ensure that all students are the benefactors of a re-formed curriculum.

Exploring Research Issues

Inquiry must ascertain whether the rhetoric of reform can become the hallmark of scientific literacy.

Two ambitious projects have the potential to serve as the framework for exploring the critical issues and questions of science curriculum reform. Both projects propose radical changes in the nature, structure, and content of the science curriculum. Both projects recognize that reform: a) must be comprehensive, and b) ought to transpire amid an ambiance of collegiality and collaboration. Further, they agree on several important issues: a) scientific endeavor ought to be presented as a social enterprise, thus emphasis should be placed on human thought, action, depth of understanding, and the application of science to personal and societal issues; b) learning strategies ought to be based upon a constructivist epistemology; and c) reform must ensure the scientific literacy of virtually all students.

Project 2061, sponsored by the American Association for the Advancement of Science, is a three-phase plan of purposive and sustained action focused upon the reform of education in science, mathematics, and technology. *Science for All Americans* highlights the understandings and habits of mind that all students should acquire for scientific literacy.[43] The Project on Scope, Sequence, and Coordination (SS&C), initiated by the National Science Teachers Association, calls for the restructuring of science at the secondary level. SS&C recommends that all students study science every year for six years, and advocates carefully sequenced, well-coordinated science instruction of all the sciences. As opposed to the traditional "layer cake" curriculum, in which science is taught in year-long discrete and compressed disciplines, SS&C advocates spacing — the study of each of the sciences spread out over several years.[44]

In addition, current and forthcoming NSF material development projects at the elementary and middle school level reflect the spirit and substance of the call for reform. Several features differentiate these projects from current programs and practices, for example: a) conceptual schemes serve as content organizers; b) technology, both as content and tool, is an innovation characterizing the reform; c) fewer concepts are studied in greater depth; and d) content and teaching methods are based upon assumptions about children's learning.[45]

Inquiry must ascertain whether the rhetoric of reform can become the hallmark of scientific literacy. The following sections are intended to complement the broader issues and questions discussed previously.

Exploring Cultural and Contextual Factors

A research agenda for the implementation of a reformed science curriculum should include questions about the influence of policy, values, beliefs, and commitments at each level, as well as questions about the interactions among these levels.

Implementing a reformed curriculum requires an understanding of schools as organizations. The cultural milieus in which science teaching and learning occur must be considered. Particular attention must be paid to the interactions among teachers, students, and the curriculum within the broader, contextualized environment.

The educational process is embedded within levels of classroom, school, and community cultures. A research agenda for the implementation of a reformed science curriculum should include questions about the influence of policy, values, beliefs, and commitments at each level, as well as questions about the interactions among these levels.

The Professional and Institutional Contexts. School and classroom practice is influenced by federal, state, district, and school policy. Textbook adoption and standardized testing policies may also influence what transpires in classrooms. The following questions represent the issues that might be investigated:

What are the key attributes of effective systemic curriculum reform? What is the role of the federal and/or state government, school district and/or local school in the process of curriculum reform? What is the role of teachers, administrators, parents, community organizations, and others interested in the process of reform?

What is the function of the district's science curriculum committee? How—and to whom—does the committee make recommendations? How are recommendations enacted?

What are the policies that will get any level of government involved no more than it needs to be, but as much as it ought to be, in order that teachers, administrators, and others involved in the reform process can accomplish their goals?

What is the effect of reform initiatives in environments that have "stringent" curricular mandates vs. "less stringent" curricular mandates?

What are the criteria for assessing student performance? What are the desired student outcomes? What is the effect of curricular reform upon student performance (e.g., achievement, attitude, self-concept, conceptualization of scientific concepts)?

If administered, what effect does the reform implementation have upon standardized test scores? What value is placed upon standardized test scores?

Does the reform of the science curriculum have any impact upon the other curricular areas?

The process of curriculum reform varies widely. Reforms on a large-scale basis may differ from sites that espouse school-based management and local school curriculum decision-making.

How does the conceptualization and implementation of curriculum reform differ in large-scale efforts vs. in the context of school-based management?

Do teachers and administrators at different schools vary in their participation, acceptance, or resistance to reform initiatives? What are the specific encouragements and constraints articulated by stakeholders in each school? What characteristics are common or unique to each participating school?

What are the issues and concerns that must be addressed during the planning phase? Do the issues and concerns differ from school to school? What are the school-based issues vs. district-level issues vs. state-level issues?

What practical and logistical issues must schools confront when major restructuring occurs (e.g., teacher course load and planning, scheduling, availability of resources, staff development opportunities)?

Community and School Contexts. Community values often influence instructional practice. The essence of a reformed science curriculum may contrast with the public's conception of "science." Open lines of communication should exist among parents, the community-at-large, and the school community. Inquiry could focus upon the nature of the school/community collaboration. Several school/community questions are worthy of consideration:

> *How does the reform process assist parents and the community-at-large in understanding the rationale and intended outcomes of the reform? How are members of the community able to contribute to the process? How are students able to contribute to the process?*
>
> *What linguistic conventions, social contexts or activities, and cultural models are there for everyday science in families and communities of various social groups? How do these everyday conventions, contexts, and cultures differ from those of formal science? How might translations among them be achieved?*
>
> *How do we make visible the resources students bring from home and the community to the science classroom setting?*
>
> *What is the parental degree of involvement in science curriculum reform?*
>
> *What are the parental perceptions of science and technology? Is science and technology valued within the culture?*
>
> *What is the parental exposure to and use of existing and emerging technologies? Does the variability of parental exposure to, and use of, technology within the home environment inhibit the notion of equal access to knowledge for some learners?*
>
> *What practical and logistical problems do schools encounter in the implementation process (e.g., scheduling conflicts, lack of materials)?*

What school factors influence project outcomes (e.g., school size, location, demographics, available resources, administrative support, background of teaching staff)?

Does participation in out-of-school activities increase in-school science participation and achievement?

Do certain populations of students benefit more from curriculum reform than others (e.g., issues of gender, race/ethnicity, class, ability level)?

How can reform enhance the participation in science of all students, especially students from traditionally disenfranchised and underrepresented populations?

School and Classroom Contexts. The quality of science instruction can be influenced by numerous school-level environmental factors (e.g., content selected, facilities, availability of resources and materials, management of materials, access to existing and emerging technologies, instructional practices, scheduling of teacher time, assessment protocols). Issues to consider are:

What is the nature and quality of communication and collaboration among science teachers? Do science teachers collaborate with teachers of other disciplines? Is the science curriculum coordinated with other disciplines? How do these issues contribute to — or detract from — student learning?

Do teachers possess a shared meaning of the goals of the curriculum? Do they feel adequately prepared to assume the instructional responsibilities associated with the reformed curriculum?

What are the personal, social, and/or environmental factors that either facilitate or inhibit students from accomplishing the intended outcomes of the reform?

Are some sites more effective than others in implementing the reform? What factors account for such differences?

Teaching-Learning Processes in the Classroom. The nature and roles of teachers and students in the teaching-learning process offer a fruitful area for investigation. Several questions were elicited in the section entitled, "Rethinking Curriculum Research and Practice." Inquiry could also focus on:

> *What are the shifts in meanings that are constructed and the evolution of students' understanding of their rights and obligations for participation in both the academic and social task structures involved in "doing science?"*[46]
>
> *What factors affect student outcomes?*
>
> *Is the content appropriate for the learner? Does the sequencing of activities reflect current learning theory?*
>
> *Have students' understandings of science concepts, the "connectedness" of such concepts, and the applications of such concepts been enhanced as a result of the project?*
>
> *Do students' interests in and understandings of science change as a result of the project?*
>
> *Do students recognize the distinction between rote and meaningful learning? How do changes in the curriculum affect students' views of learning?*
>
> *How does the breaking of content into smaller chunks and spreading them across time (spacing) affect student outcomes?*
>
> *How does the long-term instructional sequence that proceeds from the phenomenological to the empirical to the theoretical affect students' understandings of science?*
>
> *How does instruction that focuses on fewer ideas in greater depth (the "less is more" notion) affect students' understandings of science?*

Does the instructional environment facilitate the opportunity for every learner to construct meaningful learning?

How do teachers adapt instructional innovations? What teacher attitudinal and behavioral changes occur over time during an implementation process? What effect does teacher change have upon: their own perception of science teaching; their colleagues' perception of teaching; administrators' views of the science curriculum and instruction; and the expectations of parents and learners?

Understanding constraints and impediments to reform could be of great value both in the implementation process and in the establishment of implementation policies.

In what ways can the tools of technology enhance instruction?[47] *What is the pedagogical rationale for utilizing these tools?*

The framework offered for generating questions about the impact of cultural and contextual factors on the implementation of a science curriculum reform project should be interpreted as a beginning point. We encourage thought, deliberation, refinement, and inquiry.

Exploring Implementation

What are the policies and practices that affect the implementation phase of a curriculum reform project? This section is composed of a series of research questions followed by a brief discussion.

What are the constraints on the implementation of the various science curriculum reforms? What are some possible means of reducing the impact of these constraints? Constraints may vary considerably from one reform to another. There may be some common constraints and impediments endemic to the nature and process of reform. Understanding such constraints and impediments to reform could be of great value both in the implementation process and in the establishment of implementation policies.

To what extent are the intended curriculum reforms implemented? One of the common deficiencies of past studies of curricular change has been to measure the effects of intended changes without ascertaining whether the intended changes actually were in place. As a result, outcomes — or lack of outcomes — often have been attributed to changes that never took place, or to changes that differed from those claimed. The documentation of curriculum reform projects must give high priority to answering this question, otherwise the answers given to other questions may be seriously off target.

To what extent are there variations in the implementation of a reform across sites? What are the variables that are the most closely related to these variations? Variations in the implementation of a reform across sites are among the most promising areas of study. In particular, they are of interest when information can be acquired about the variables most closely related to these variations. Studies of this nature offer the opportunity to increase our understanding of the advantages and limitations of reform.

What approaches to school restructuring and teacher empowerment are most effective in implementing the desired science curriculum reforms? There are many indications that substantial curriculum change is unlikely to occur independently of changes in the social context of schooling. Given this potential association of curricular change and contextual change, it is important to give major consideration to the change processes occurring within the schools and their connection to curricular change. Issues associated with teacher empowerment in the context of curriculum reform and action research have been discussed previously.

Substantial curriculum change is unlikely to occur independently of changes in the social context of schooling.

How should science curriculum development, especially at the elementary level, respond to current educational movements in other areas of the curriculum (e.g., the whole language approach)? Reform in other curricular areas has the potential of enhancing science. For example, the increasingly popular whole language approach, with its decreased emphasis on facts and drill, has the potential of leading to less emphasis on narrowly-defined paper-and-pencil tests. Ideally, this could serve as a stimulus for integrated programs of instruction in which good activity-based science instruction might ensue. On the other hand, the result may well be more reading about science and less time devoted to science activities. Studies should aim at understanding how comprehensive restructuring and reform can facilitate the needs of each of the disciplines. Research could similarly focus on efforts to address interdisciplinary curriculum design and implementation.[48]

To what extent do educational leaders' and practitioners' conceptions of the nature of science, schools, teaching, and curriculum constrain possible reforms? People's views of the goals of science education, their ideas about how students learn, and their views of science and its role in our society are among those perspectives profoundly influencing what reforms they favor and the manner in which they are willing to see them implemented. Understanding the convictions as well as concerns of the various personnel involved — especially teachers — is important for determining what reforms are feasible and how best to go about initiating and sustaining such changes.

People's views of the goals of science education, their ideas about how students learn, and their views of science and its role in our society are among those perspectives profoundly influencing what reforms they favor and the manner in which they are willing to see them implemented.

To what extent are classroom aspects, such as the following, changed as a result of reforms: classroom social environments, the means of monitoring and responding to student understanding, academic tasks, and teaching strategies? Understanding the impact of reforms on a wide variety of variables — not just student learning — is essential to assessing their potential for change and the circumstances under which they can be initiated successfully. The impacts potentially are large; a curricular change has the potential of influencing many variables in a given situation.

Successfully implementing curricular change is not easy. Understanding the process better should increase the potential of successfully making the intended changes. Answers to the above questions would go a long way in providing understanding.

Exploring the Impact

Fundamental questions about curriculum reform concern impact and effectiveness. Proponents and potential implementers of reforms will want to know whether the reforms achieved their stated goals. Unintended or unexpected outcomes may also be of interest. Three broad, organizing questions serve as the focus for inquiry regarding the impact and effectiveness of curriculum reform:

What are the effects of reform initiatives on students?

What are the effects of reform initiatives on teachers?

What factors moderate the effects of reform?

What are the Effects of Reform Initiatives on Students? A large number of very detailed questions can be imagined that would tap different aspects of the effects or outcomes of curriculum reform. Two critical outcomes to be considered are students' understandings of science — in the broadest sense — and attitudes towards science.

Two bodies of research can help us develop much more sophisticated images of what it means for a student to understand something scientifically. First, ideas about cognitive science or conceptual change in science learning. Second, research focusing on how people learn, as well as how they use language as they participate in the activities of communities.[49]

Innovative assessment must also be an integral part of curriculum reform. This statement does not conflict with our previous discussion on standardized assessment. New forms of assessment technology ought to derive from recent theory and research in cognitive and motivational psychology. They should be applied to effective learning environments. Dynamic assessment should be designed to evaluate students' potential for change by assessing process rather than product.[50] "Research might take the lead in the reform of indicators of science achievement. Researchers, in partnership with practitioners, need to build a new knowledge base and a new technology for achievement in science."[51]

What are the Effects of Reform Initiatives on Teachers? As teachers implement a reformed curriculum, they will be affected by the curriculum as well. Questions of interest are:

What is the impact on teachers' activities and behaviors in the classroom and beyond?

How do teachers collaborate to achieve the bridging and coordination between subject-matter areas that are desired? What strategies do teachers introduce to help strengthen these connections?

How do teachers use materials to facilitate student learning and student involvement in learning?

What changes can be expected in strategies and material usage when teachers implement the curriculum?

Another area of impact will be upon the beliefs and attitudes of teachers about their practice, their students, and the subject matter.

How will teachers feel about developing, planning, and implementing a curriculum which involves extensive cooperation among teachers (and administrators)?

How will the introduction of reform affect teachers' motivation and satisfaction with their practice? Do teachers envision reform as providing mostly opportunities, or as presenting problems?

Science education must become more responsive to personal, societal, and cultural needs.

Teachers' attitudes towards their students may change as students become more active in their own learning and begin to make connections across science subject-matter areas. Teachers' responses to the changes in their students may vary according to characteristics of the teachers themselves. For instance, teachers who feel competent to deal with topics at the boundaries of their subject-matter areas may be pleased with student initiative, while less confident teachers may feel threatened. Finally, it will be important to note the extent to which teachers encourage active participation in science for all students.

What Factors Moderate the Effects of Reform? Understanding what individual and group differences act to enhance (or reduce) the effectiveness of science instruction should be a main goal of research on this question.

Gender, ethnicity, and class status are three variables that bear investigation in any research on moderators of curriculum effects. In science education these are particularly important variables to study because of the current patterns of participation in science- and technology-oriented careers. An overt goal of every major science reform initiative is to promote more interest and persistence in science by all students. Thus, gender, ethnicity, and class are important moderator variables to investigate.

The Foreseeable Future

Science education must become more responsive to personal, societal, and cultural needs. Reform and restructuring will be the way of life for the foreseeable future. Presently, a great deal of progress is being made in combining technological advances with insights into science learning and science instruction. Reform will ultimately involve a redefinition of the roles of teachers, researchers, technology, textbooks, and other influences associated with the process of schooling.[52] New infrastructures — organizational and technological — will be necessary to support the process of change in science education.

In addition to ensuring that all students develop a scientific literacy, to enable full and active participation as citizens in a democratic society, we must begin to attract students to careers in science and technology.

The science education community must ensure that students receive the best science education that can be offered. Ensuring congruence between what is needed and what is offered can be accomplished through adherence to policies that are research supported. In addition to ensuring that all students develop scientific literacy, to enable full and active participation as citizens in a democratic society, we must begin to attract students to careers in science and technology, as well. Enhancing students' interest and participation in science and technology will require broad-based community initiatives in concert with appropriate educational interventions. Enhancing scientific and technological literacy and career awareness is as much a socio-cultural and political issue as it is an educational issue.

Recommendations

Science educators have been searching for the wonder drug for over twenty-five years. At one time or another, the search has focused upon: *the* curriculum ... *the* instructional strategy ... *the* teacher ... *the* learner ... *the* technology ... *the* research study that would solve the pressing issues of the day. The search has typically involved a single investigator who: isolates one variable at a time in a controlled "laboratory" environment; oversimplifies the variable for the purpose of inquiry; and celebrates victory at the discovery of a new significant difference. The isolation of variables has isolated researchers from the rest of the world. The quick, one-shot approach to research contrasts with emerging curricular notions of depth vs. breadth and long-term coordination vs. isolated knowledge. The personal celebrations of victory are at odds with the recognized hallmarks of reform — collaboration and communication.

We must construct a comprehensive, intellectually honest, and pedagogically valid image of reform.

Why have efforts to improve science teaching through research typically failed? Inquiry and debate have not addressed the issues of sustainable reform: *the* process of change ... *the* culture of schools ... *the* context of classrooms ... *the* content of the curriculum.[53] Curriculum, instruction, assessment, and research in science education must be reformed. We must construct a comprehensive, intellectually honest, and pedagogically valid image of reform. This emerging image must:

* ensure that citizens develop scientific and technological literacy for self- and social-empowerment;

* address the wider socio-cultural, economic, and political contexts in which schooling transpires; and

* ensure that scientific literacy for all means just that — literacy for all.

We set out to identify the critical issues and questions of science curriculum reform. We offer the following recommendations:

1. **Long-term, comprehensive research projects must be initiated.** These projects ought to focus on both the process and impact of reform. These projects should encourage the creation of research networks. Projects of this nature have the potential to: ensure that a sound theoretical framework underpins the systemic inquiry of science curriculum reform;

improve the quality of research; and contribute to sustainable reform.

2. **Communication and collaboration must be valued.** Our understanding of science teaching and learning will be enhanced by practitioners and researchers theorizing, planning, conducting, and interpreting research that is pedagogically valid. Enhanced communication and collaboration should inform the process and influence practice.

3. **The reform of schools and teacher education must be in harmony.** The reform of schooling requires nothing less than the transformation of the way prospective teachers are educated.[54]

4. **Novel and practical ways to share experiences of curriculum reform research must be identified.** Few research reports are read by the people for whom the reports could have the greatest implications — teachers, administrators, policy makers, and curriculum material developers. An effective program of research related to curriculum reform will require an equally effective system for sharing what is learned. Non-traditional avenues and forms of reporting research must be explored.

Can we learn to become conscious of the issues that face us collectively? In order to do so, we must become *new-minded*.[55] Our comprehension of issues, problems, and problem resolution must be viewed from the long-term vs. short-term perspective. People's ideas are not as fixed as commonly thought. Thus, our chances of becoming new-minded and successfully confronting the formidable challenges before us are greatly enhanced.

Notes

1. Joseph Rouse, *Knowledge and Power: Toward a Political Philosophy of Science* (Ithaca, NY: Cornell University Press, 1987), pp. viii & 3.

2. Edward Wenk, Jr., *Tradeoffs: Imperatives of Choice in a High-Tech World* (Baltimore, MD: The Johns Hopkins University Press, 1989), pp. 6 & 9.

3. Rouse, *Knowledge and Power*, pp. 3, 6, & 248-265.

4. These questions are raised by Rouse (1987) in the context of philosophical inquiry into the practical, social, and political dimensions of science, see pp. viii, x, & 6. We believe these questions are equally viable in the context of critical issues related to science curriculum reform. These questions complement two issues raised by participants: "*How can the nature of science be used to inform instruction?*" and "*What are the social and societal barriers to students' learning of science?*"

5. Lester R. Brown et al., *State of the World 1991* (New York: W. W. Norton, 1991), pp. 3, 20, 188, & Ch. 10.

6. William C. Kyle, Jr., "The Reform Agenda and Science Education: Hegemonic Control vs. Counterhegemony," *Science Education*, in press.

7. Richard H. Schlagel, *Contextual Realism: A Meta-physical Framework for Modern Science* (New York: Paragon House, 1986), p. xxxi.

8. William C. Kyle, Jr., *Improving Science Teaching: Beyond Epistemological Arguments of the Positivist and the Interpretive Views of Research toward a Conception of Dialogical Communities* (West Lafayette, IN: Purdue University, School Mathematics and Science Center, 1991).

9. For further explication of the issue of schooling and cultural production, see Michael W. Apple, *Teachers and Texts: A Political Economy of Class and Gender Relations in Education* (New York: Routledge & Kegan Paul, 1986); Paulo Freire, *The Politics of Education: Culture, Power, and Liberation*, trans. by D. Macedo (Granby, MA: Bergin & Garvey, 1985); Henry A. Giroux, *Schooling and the Struggle for Public Life: Critical Pedagogy in the Modern Age* (Minneapolis, MN: University of Minnesota Press, 1988); Henry A. Giroux & Peter McLaren, eds., *Critical Pedagogy, the State, and Cultural Struggle* (Albany, NY: State University of New York Press, 1989); Jeannie Oakes, *Multiplying Inequalities: The Effects of Race, Social Class, and Tracking on Opportunities to Learn in Mathematics and Science* (Santa Monica, CA: RAND, 1990); Jeannie Oakes, "Opportunities, Achievement, and Choice: Women and Minority Students in Science and Mathematics," in Courtney B. Cazden, ed., *Review of Research in Education*, vol. 16, pp. 153-222 (Washington, DC: American Educational Research Association, 1990); Lois Weis, ed., *Class, Race, and Gender in American Education* (Albany, NY: State University of New York Press, 1988).

10. Peter McLaren, *Life in Schools: An Introduction to Critical Pedagogy in the Foundations of Education* (New York: Longman, 1989), p. 158.

11. William C. Kyle, Jr., A Meta-analysis of the Effects on Student Performance of the New Curricular Programs Developed in Science Education Since 1955 (*Dissertation Abstracts International, 43*, 1104A, 1982), p. 16. Laurel N. Tanner discussed the need to integrate curriculum history in both curriculum reform and research in "Curriculum History and Educational Leadership," *Educational Leadership*, November 1983, pp. 38-42.

12. These questions were raised in the context of investigating historical changes in the goals of science education for the purpose of suggesting policies for future decades in Rodger W. Bybee, "Historical Research in Science Education," *Journal of Research in Science Teaching*, vol. 19, 1982, pp. 1-13. The questions are italicized because they were also raised by conference participants.

13. Merle Miller, *Plain Speaking: An Oral Biography of Harry S. Truman* (New York: G.P. Putnam's Sons, 1973).

14. For an overview of the educational achievements of the reform efforts of the 1960s, see James A. Shymansky et al., "The Effects of New Science Curricula on Student Performance," *Journal of Research in Science Teaching*, vol. 20 1983, pp. 387-404 and James A. Shymansky et al., "A Reassessment of the Effects of Inquiry-Based Science Curricula of the '60s on Student Performance," *Journal of Research in Science Teaching*, vol. 27, 1990, pp. 127-144.

15. Between 1854 and 1859, Herbert Spencer wrote and published separately four essays on education. In 1861 the four essays appeared in a single volume entitled, *Education: Intellectual, Moral, and Physical*. The tone of the publications was aggressive. While the proposals were revolutionary, Spencer noted that many of the ideas were synthesized from earlier writers on education. However, the new doctrine that ran throughout all of the essays was most fully articulated in the 1859 essay entitled, "What Knowledge is of Most Worth?" See Herbert Spencer, *Essays on Education* (London: J.M. Dent & Sons, 1911).

16. See Oakes, *Multiplying Inequalities*; William Reese, *Power and the Promise of School Reform* (New York: Routledge & Kegan Paul, 1986); Weis, ed., *Class, Race, and Gender in American Education*.

17. For further elucidation of this point, see Michael W. Apple, *Ideology and Curriculum*, 2nd ed. (New York: Routledge & Kegan Paul, 1990).

18. Jeanne Oakes, "Tracking in Mathematics and Science Education: A Structural Contribution to Unequal Schools," in Lois Weis, ed., *Class, Race, and Gender in American Education*, pp. 106-125.

19. Elliot W. Eisner, "Who Decides What Schools Teach?" *Phi Delta Kappan*, March 1990, 523-526.

20. Throughout this report we use the umbrella "qualitative" for the methodologies that include case study, ethnographic, and naturalistic inquiry. The reader may wish to refer to: Robert C. Bogdan & Sari Knopp Biklen, *Qualitative Research for Education: An Introduction to Theory and Methods* (Boston: Allyn and Bacon,

1982); Frederick Erickson, "Qualitative Methods of Research on Teaching," in Merlin C. Wittrock, ed., *The Handbook of Educational Research*, 3rd ed., pp. 119-161 (New York: Macmillan, 1986); Judith Preissle Goetz & Margaret Diane LeCompte, *Ethnography and Qualitative Design in Educational Research* (San Diego, CA: Academic Press, 1984); and Yvonna S. Lincoln & Egon G. Guba, *Naturalistic Inquiry* (Beverly Hills, CA: Sage Publications, 1985).

21. Marcia C. Linn, "Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations," *Journal of Research in Science Teaching*, vol. 24, 1987, pp. 191-216.

22. Kyle, "The Reform Agenda and Science Education."

23. For a convincing critique of the productive and reproductive aspects of schooling, see Michael W. Apple, *Education and Power* (Boston: Routledge & Kegan Paul, 1982). For an overview of various perspectives of social transformation, see McLaren, *Life in Schools*. Refer to the works of John Dewey for further explication of his notion of education, inquiry, and social transformation, see especially *Liberalism and Social Action* (New York: G.P. Putnam's Sons, 1935), *Experience and Education* (New York: Macmillan, 1938), *Democracy and Education: An Introduction to the Philosophy of Education* (New York: Macmillan, 1916), and *Freedom and Culture*, (G.P. Putnam's Sons, 1963, c1939).

24. William C. Kyle, Jr. et al., "The Role of Research in Science Teaching," *Science Education*, in press.

25. Peter J. Fensham, "Familiar but Different: Some Dilemmas and New Directions in Science Education," in Peter J. Fensham, ed., *Development and Dilemmas in Science Education*, pp. 1-26 (New York: The Falmer Press, 1988).

26. We offer these four principles in light of the emerging educational reform and curriculum research ethos, which views both processes as participatory and collaborative. Thus, research is directed at critical analysis of situations and problems with a view toward transforming schools and classrooms in ways that will improve the situation for students, teachers, and society. This contrasts with the curriculum development era of the 1960s and early 1970s, which legitimated and sustained the separation of theory from practice and research from action. The emerging ethos questions the model of technical rationality as applied to curriculum and curriculum research. The model of technical rationality has forged a wide gulf between researchers and practitioners. The emerging ethos is guided by critical reflection and its epistemology is constructivist. See, for example, Wilfred Carr & Stephen Kemmis, *Becoming Critical: Education, Knowledge and Action Research* (Philadelphia: The Falmer Press, 1986); Donald A. Schon, *The Reflective Practitioner: How Professionals Think in Action* (New York: Basic Books, 1983); Donald A. Schon, ed., *The Reflective Turn: Case Studies In and On Educational Practice* (New York: Teachers College Press, 1991); Ernst von Glasersfeld, "An Introduction to Radical Constructivism," in Paul Watzlawick, ed., *The Invented Reality*, pp. 17-40 (New York: W.W. Norton, 1984). See also, Sharon Nodie Oja & Lisa Smulyan, *Collaborative Action Research: A Developmental Approach* (New York: The Falmer Press, 1989).

27. Personal communication, Walter C. Parker to William C. Kyle, Jr., July 1990. Walter C. Parker is author of the forthcoming book entitled, *Renewing the Social Studies Curriculum* (Alexandria, VA: Association for Supervision and Curriculum Development).

28. Larry Cuban, "Reforming Again, Again, and Again," *Educational Researcher*, January 1990, pp. 3-13.

29. Research on educational change and staff development offers recommendations for how to implement educational innovations. See, for example, Michael Fullan, *The Meaning of Educational Change* (New York: Teachers College Press, 1982); Gene E. Hall & Shirley M. Hord, *Change in Schools: Facilitating the Process* (Albany, NY: State University of New York Press, 1987); Shirley M. Hord, William L. Rutherford, Leslie Huling-Austin & Gene E. Hall, *Taking Charge of Change* (Alexandria, VA: Association for Supervision and Curriclum Development, 1987).

30. For further explication of the constructivist epistemology, refer to Ernst von Glasersfeld, *The Construction of Knowledge* (Seaside, CA: Intersystems Publications, 1987). The National Science Foundation has funded eight major (and several other) elementary material development programs that lean toward constructivist teaching and learning. The reforms advocated by the American Association for the Advancement of Science and the National Science Teachers Association recognize the importance of a constructivist epistemology. See F. James Rutherford & Andrew Ahlgren, *Science for All Americans* (New York: Oxford University Press, 1990) and Bill G. Aldridge, "Essential Changes in Secondary School Science: Scope, Sequence, and Coordination," *NSTA Reports!*, January/February 1989, respectively. The following publications offer suggestions for teaching practices: Christine Chaille & Lory Britain, *The Young Child as Scientist: A Constructivist Approach to Early Childhood Science Education* (New York: Harper Collins Publishers, 1991); Audrey Champagne & Leslie E. Hornig, eds., *This Year in School Science 1986: The Science Curriculum* (Washington, DC: American Association for the Advancement of Science, 1986); Susan Loucks-Horsley et al., *Elementary School Science for the '90s* (Alexandria, VA: Association for Supervision and Curriculum Development, 1990); Robin Millar, ed., *Doing Science: Images of Science in Science Education* (New York: The Falmer Press, 1989); Roger Osborne & Peter Freyberg, *Learning in Science: The Implications of Children's Science* (Portsmouth, NH: Heinemann, 1985).

31. The theory of "knowledge constitutive interests" is described in Jurgen Habermas, *Knowledge and Human Interests*, trans. by J. J. Shapiro (London: Heinemann, 1972). See also, Richard J. Bernstein, *Beyond Objectivism and Realism: Science, Hermeneutics, and Praxis* (Philadelphia: University of Pennsylvania Press, 1988) and Carr & Kemmis, *Becoming Critical*, p. 136.

32. See Kenneth Tobin, Jane Butler Kahle & Barry J. Fraser, *Windows into Science Classrooms: Problems Associated with Higher-Level Cognitive Learning* (New York: The Falmer Press, 1990).

33. Mark Johnson, *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason* (Chicago: The University of Chicago Press, 1987).

34. The litany of education reports in the United States since 1980 is too numerous to cite. Suffice it to say, however, that the tone for many of these reports was established by The National Commission on Excellence in Education's report entitled, *A Nation at Risk: The Imperative for Educational Reform* (Washington, DC: U.S. Government Printing Office, 1983). The most recent report focusing upon international competitiveness rather than international cooperation is the Report of the FCCSET Committee on Education and Human Resources, *By the Year 2000: First in the World* (Washington, DC: Office of Science and Technology Policy, 1991).

35. Kyle, "The Reform Agenda and Science Education."

36. The International Association for the Evaluation of Educational Achievement (IEA) conducted a study of the achievement in science in 19 countries in 1970. The Second International Science Study (SISS) was repeated in the mid-1980s with 24 countries participating. See IEA, *Science Achievement in Seventeen Countries: A Preliminary Report* (New York: Pergamon Press, 1988). The international results are reported for three populations: Population 1 (10 year olds), based upon a 24-item core test and two shorter 8-item tests; Population 2 (14 year olds, purportedly of great importance because this is the point near the end of compulsory education and the science achievement levels are one indicator of how scientifically literate the general public and work force will be, p. 42), based upon a 30-item core test and two shorter 10-item tests; and Population 3 (students in the final year of secondary school, purportedly representing the scientific elite in a technological era — those specializing in science, p. 43), based upon a 30-item core test, as well as separate discipline tests for students studying biology, chemistry, or physics, or a special non-science test for those students not studying science. Due to the diverse educational systems and curricular emphases, the IEA constructed three indices of test validity (a curriculum relevance index, a test relevance index, and a curriculum coverage index). While these tests may offer interesting international insights, we question why any country would aspire to being "number one" on a test with such a narrow perspective of achievement. It is difficult to imagine how interpretations of these results could offer any meaningful guidance or assessment of curriculum reform.

37. National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, *Educating Americans for the 21st Century: A Plan of Action for Improving Mathematics, Science, and Technology Education for All American Elementary and Secondary Students so that Their Achievement is the Best in the World by 1995* (Washington, DC: National Science Foundation, 1983).

38. Governor Roy Romer of Colorado as quoted in, "Nation Just Out of the Starting Gate on Education Goals," *Report on Education Research*, January 9, 1991, p. 4.

39. Refer to Paulo Freire, *Pedagogy of the Oppressed* (New York: Seabury Press, 1970); Paulo Freire, *Education for Critical Consciousness* (New York: Seabury Press, 1973); and Freire, *The Politics of Education*.

40. J. Myron Atkin, "Can Educational Research Keep Pace with Educational Reform?" *Phi Delta Kappan*, November 1989, pp. 200-205.

41. Rutherford & Ahlgren, *Science for All Americans.*

42. Personal communication, Albert V. Baez to William C. Kyle, Jr., July 1989.

43. Rutherford & Ahlgren, *Science for All Americans.*

44. Aldridge, *"Essential Changes in Secondary School Science."*

45. See Rodger W. Bybee, "Contemporary Elementary School Science: The Evolution of Teachers and Teaching," in Audrey B. Champagne, ed., *This Year in School Science 1988: Science Teaching*, pp. 153-171 (Washington, DC: American Association for the Advancement of Science). See also, The National Center for Improving Science Education's series of reports entitled, The Elementary Years and The Middle Years. Each series is comprised of four reports available through: The Network, 300 Brickstone Square, Suite 900, Andover, MA.

46. See J. L. Lemke, *Using Language in the Classroom* (Oxford: Oxford University Press, 1989) and J. L. Lemke, *Talking Science* (Norwood Hills, NJ: Ablex, 1990).

47. See James D. Ellis, ed., *1988 AETS Yearbook: Information Technology and Science Education* (Columbus, OH: ERIC Clearinghouse, 1989).

48. Heidi Hayes Jacobs, ed., *Interdisciplinary Curriculum: Design and Implementation* (Alexandria, VA: Association for Supervision and Curriculum Development, 1989).

49. The literature on cognitive science or conceptual change in science learning would be too numerous to cite. Instead, we refer the reader to #30 above, in particular Millar, *Doing Science* and Osborne & Freyberg, *Learning in Science*. Refer to the following sources regarding the second body of research: Barbara Rogoff & Jean Lave, eds., *Everyday Cognition: Its Development in Social Context* (Cambridge, MA: Harvard University Press, 1984) and Les Vygotsky, *Thought and Language* (Cambridge, MA: M.I.T. Press, 1962).

50. See Audrey B. Champagne, Barbara E. Lovitts & Betty J. Calinger, eds., *This Year in School Science 1990: Assessment in the Service of Instruction* (Washington, DC: Association for the Advancement of Science, 1990).

51. Richard J. Shavelson, Neil B. Carey & Noreen M. Webb, "Indicators of Science Achievement: Options for a Powerful Policy Instrument," *Phi Delta Kappan*, May 1990, pp. 692-697.

52. Marcia C. Linn, "Science Education and the Challenges of Technology," in James D. Ellis, ed., *1988 AETS Yearbook: Information Technology and Science Education*, pp. 119-144 (Columbus, OH: ERIC Clearinghouse, 1989).

53. Ann Lieberman, "Navigating the Four C's: Building a Bridge over Troubled Waters," *Phi Delta Kappan*, March 1990, pp. 531-533.

54. See The Holmes Group, *Tomorrow's Schools: Principles of the Design of Professional Development Schools* (East Lansing, MI: Author, 1990). See also John I. Goodlad, *Teachers for Our Nation's Schools* (San Francisco: Jossey-Bass, 1990).

55. Robert Ornstein & Paul Ehrlich, *New World New Mind* (New York: Simon & Schuster, 1989).

Acknowledgements

We wish to thank Mark J. Volkmann for his comments and suggestions for improvement. Mark is completing a Ph.D. in science education at Purdue University. He is investigating issues associated with the process of reform. His recommendations were most valued from the perspective of a classroom teacher — for nineteen years — who has been interested in the issues of reform, empowerment, and classroom-based research. We also wish to thank Bonnie Nowakowski for editing and proofing the document. Any remaining errors or omissions are the responsibility of the authors.

PRINTED ON RECYCLED PAPER