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ABSTRACT

As powerful as the compelling reasons for reform in science education are, there is also uncertainty about where this reform may lead. This special issue focuses on reform in K-12 science education. The 23 articles in this book are placed in the following sections: (1) In this issue, (2) Project 2061, (3) The Scope, Sequence and Coordination (SS&C) Project, (4) Teacher Preparation, (5) Science Assessment, (6) Technology in Science Education, (7) Earth Science Education, and (8) Biotechnology Education. (PR)

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IN THIS ISSUE . . .

Editor's Corner

Reforms in Science Education, K-12

Kathleen A. O'Sullivan

This special issue of the *School of Education Review* focuses on reform in K-12 science education. The need to improve the scientific literacy of our children through collaborative efforts has never been more clear for they will depend more than ever upon scientific understandings of the natural world and technological applications of those understandings. While the majority of our children will not be the future scientists and technicians to develop further our understandings and applications, all of them will be users, consumers, and, most important, decision makers about issues of science and technology.

These needs and our increased knowledge of how people learn have been the impetus for reform in science education. To that end, the response of organizations and individuals at the national, state, and local levels has been significant and sustained. The collaborative participation of governments, professional organizations in education and the sciences, educational institutions and agencies, and teachers themselves has already fostered change. The task of reforming K-12 science education is not over, and perhaps, like science itself, can never be completed, but even the most skeptical observer must admit that we have embarked upon the journey and have gained the momentum needed to continue the reform.

As powerful as the compelling reasons for reform in science education, there is also uncertainty about where this reform may lead. Just as Columbus began a voyage with unforeseen ends, five hundred years later (i.e., Columbus Day, 1992), NASA implemented the High Resolution Microwave Survey to search for radio waves from extraterrestrial civilizations about whose existence we can only surmise. In this issue of the *SOE Review*, we attempt to map some of the geography of the journey in science education as it is occurring in the nation, in California, and in the San Francisco Bay Area. California is widely recognized as a leader and key contributor to the reform movement. Moreover, the Bay Area has been an important participant in these areas of reform. The same could be said of many other regions; the reader is asked to keep in mind that these individuals and their efforts are examples of thousands of others who work most directly with the ultimate target, our children.

In this special issue, the first group of three articles deals with one of two national reform projects in science education. Project 2061, sponsored by the American Association for the Advancement of Science (AAAS), is a long term, comprehensive initiative which is developing curriculum models, benchmarks for science literacy, and blueprints for changes in other system aspects. Following James Rutherford's national perspective, Phil Gay provides an historical perspective of California's role as the home of two of the six school district sites where Project 2061 is taking place. Bernard Farges then describes the San Francisco curriculum model.

The second section of three articles treats the Scope, Sequence and Coordination (SS&C) Project initiated and coordinated by the National Science

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Teachers Association (NSTA). Linda Crow and Bill Aldridge provide an overview of this major, national reform effort to restructure secondary school science with its spaced and spiralled curriculum model based on the most current learning research. California's SS&C Project, involving 199 schools throughout the state, is described by Tom Sacshe. Efforts at San Francisco's Burton High School, one of these 199 schools, are addressed by Robin McGlohn.

Any reform, and especially reform in an area or system as broad as science education, requires attention to changes in its multiple dimensions. Two sections of the *Review* deal with science teacher education and assessment, two critical areas which have been targeted for dramatic revisions. Steve Gilbert writes on the science teacher preparation standards of the National Council for the Accreditation of Teacher Education (NCATE) and NSTA. The multiple factors affecting both preservice and inservice teacher education in California are examined by Bonnie Brunkhorst. Mary Hamm provides the perspective on university preparation of elementary school science teachers.

Three of the recurring issues in assessment reform are explored by Angelo Collins: purpose, alternative assessment, and equity. We see these issues detailed in Kathleen Comfort's description of the California Assessment Program (CAP) and again in Erla Hackett and Susan Floore's review of their experiences as classroom teachers piloting the CAP's new performance assessments.

Technology in science education has multiple meanings illustrated by all three articles which here address technology. Patricia Freitag approaches the topic from a broadly based view of its roles in science education research. Karen Reynolds reviews the history and current environment of technology in science education in California. And Conrad Mezzetta and Lyn Chan describe what happens for kids in school when dedicated classroom teachers meet the challenge.

Our final articles focus on specific areas of the curriculum with particular meaning for California schools: earth sciences and biotechnology. Greg Wheeler and Crellin Pauling, respectively, provide the national and particular state perspectives in these areas, both of which have gained considerable momentum for growth in recent years. Ellen Metzger describes the Bay Area Earth Science Institute (BAESI), a collaborative effort of a wide variety of professionals to improve earth science teacher preparation and teaching. Finally, from the San Mateo County, California, biotechnology program, Sue Black, Kathy Liu, and Stan Ogren demonstrate again the difference classroom teachers make.

While hardly comprehensive and more aptly seen as the unfinished log of a journey, we hope that this selection of articles on reform in science education will inform and encourage you. And we also immodestly hope that the commitment and enthusiasm of these contributors has a multiplier effect, for in the words of two of them, "it's an exciting time to be a science educator."

Another National Deficit: Shortage of Technical Students

J. N. Sullivan

More than a century ago, Ralph Waldo Emerson claimed that the truest measure of a nation's greatness is not the size of its population, its cities or its crops, but the quality of the people it produces. That idea is even more pertinent today as our nation faces greater competition in an increasingly complex and interwoven global economy.

In *Mega Trends 2000*, John Naisbitt updated Emerson's thought while looking to the future. As we approach a new millennium, Naisbitt observed, "human resources are the competitive edge for both companies and countries. In this global economic competition . . . the quality and innovativeness of human resources will spell the difference." I'd sharpen the focus of that modern-day statement even more: today, the quality of our nation's work force must be measured by its technological expertise.

While the service sector has surged in recent years, our nation's economic strength still rests on the health of our manufacturing sector. Engineers and scientists help to create, rather than redistribute, a nation's wealth. Relying on advanced mathematics, chemistry and physics, they create useful products that can boost a nation's productivity and efficiency. As a result, it's clear that professionals schooled in the technical disciplines, especially chemistry and engineering, will increasingly shape the future.

At Chevron, more than 40 percent of the new professionals we hire are recent engineering graduates. Solid grounding in the hard sciences makes engineers skilled problem-solvers, whether reformulating cleaner gasolines, building pipelines over forbidding terrain, or finding new ways to make operations and organizations more cost-effective. With continuing progress in computer, information and biotechnology industries, demand will also accelerate for engineers and scientists trained in those fields. Unfortunately, the talent pool for such valued "creators of wealth" is quickly drying up in the United States. Personally, I'd describe this situation as a national crisis: *one that ranks in importance with our country's out-of-control national debt.*

The dwindling supply of technical talent in the United States is probably the fault of both industry and educational institutions. Frankly, neither has done an adequate job of attracting and training enough people in the hard sciences, (e.g., because of changing technologies the National Science Foundation projects a shortage of 600,000 engineering and science graduates by the turn of the century). If educating more people in the technical disciplines does not become a national priority immediately, I'm afraid our nation's future ability to compete and our quality of life will suffer dramatically.

We must pay attention to the fact that during this decade as our economy continues to grow, the number of college age students in the U.S. will be dropping. At the same time, women and minorities who will comprise nearly half our nation's work force will be a key to that future work force. Thus, a majority of America's work force will come from the very groups that have been under-represented in technical and scientific disciplines. Both

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business and education must do more to attract and train our increasingly diverse human resources. Equally disturbing is the fact that other developed nations are better at cultivating their technical work forces. Japan, for example, has only half the population of the United States but nearly the same number of engineers, about 1.5 million, and has been producing them at a much faster pace. The long-term implications of all this represent one of the major challenges facing American industry--and education--in the decade ahead.

These inter-related problems are easy to identify, but the solutions are not easy to find. We do know that there are no quick fixes here--no one-time magic potions.

Nonetheless, I think this nation has the creative genius, the resources and the conviction to get back on the right course--if we just work together toward common goals. The federal government may provide broad guidance and leadership, but the practical solutions are local ones. Changes in curriculum and in emphasizing the fourth "R"--Workforce Readiness--must come state by state, district by district, school by school and classroom by classroom. Consequently, I'm convinced that the best way to stimulate greater interest in the hard sciences is for business and education to form more partnerships in the communities where we live and work.

Such partnerships can only occur when the entire community works together in the pursuit of a lifelong career of learning. At Chevron, we've been involved in educational betterment for more than 60 years. More than half our annual $20 million contributions budget is earmarked for educational programs. In recent years, however, we've realized that we must help support more innovative approaches in the classroom, and that we must get more personally involved. As a result, we re-evaluated our contributions strategy.

Because the United States already has some of the greatest institutions of higher learning in the world, we concluded that companies like ours can make the biggest difference by increasing support for pre-college programs, programs that not only help encourage excellence in math and science, but also encourage family participation and teacher training. For example, we support "Family Science," aimed at females and minorities, which gets teachers, students and parents to learn and enjoy science together. We're also excited about a new program called "Accelerated Schools," which speeds up--rather than slows down--education for disadvantaged students in the elementary grades.

But we also realize that we must do a lot more than take the traditional corporate approaches to education. In a program called "Encore," Chevron is helping retired employees find new careers in teaching, especially in math and science. We also provide summer internships for teachers that help provide fresh perspective and, hopefully, that result in new approaches in the classroom.

Above all, we encourage our employees to get involved in their local schools. During National Engineering Week, I join with other senior managers of Chevron to talk to school-age students about technical careers. I know first-hand how difficult it is to get students excited about being engineers or scientists, especially when television shows like "L.A. Law" or "Miami Vice" make other careers seem more inviting.

Business is ready, willing, able--and almost desperate--to help in this national campaign for a more technically educated work force. And it's not just the professionals that we need. We're living in an increasingly computerized world where virtually everyone--from the executive in the boardroom to the clerk in the mail room--must not only think critically and creatively, but also demonstrate more technological proficiency.

We still have a nation rich in resources, ideas and talent. We can do the job, but it will take all of us working together to get it done right. Nothing less than our nation's ability to compete and to sustain our quality of life is at stake.

Responding to the Crisis in Science Education

Robert A. Corrigan

Ever since Sputnik, worried educators have assessed the science and mathematics skills of our nation's children, often finding them wanting when compared with their peers elsewhere.

Fresh evidence that we still have a problem arrived recently in the form of a survey of America's international competitiveness, measured by such indices as economic strength, technological and scientific advances and management skills.

The survey, which received surprisingly little news media attention, revealed a dramatic drop–from second to fifth place in just one year. What the report found most alarming for our long-term competitiveness was the U.S. drop in the "quality of its people"–from second position to seventh this year.

That decline, the survey found, was caused in part by the inability of the U.S. educational system to meet the needs of a competitive economy.

The National Science Teachers Association (NSTA) admits that indeed, our schools "are failing to educate students for a world that depends more and more on sophisticated and rapidly changing science and technology." It suggests that schools are neither meeting the nation's demand for scientists and engineers nor giving future citizens the scientific literacy they need to participate in decisions affecting their lives and the world.

But the picture is not all bleak. Across the nation, groups of creative and dedicated educators are leading a wave of reform. They are working to change the way we teach science, mathematics and technology, to try new paths to unlocking the curiosity and the talent that we know is there in our students.

Those efforts, which are gathering momentum and gaining increasing attention, are the subject of this issue of the *Review*. As you will read, San Francisco State University is a partner in a number of innovative science education projects. We have, in one conspicuous instance, provided state and even national leadership by creating programs to update science teachers in a field that was born in our state–biotechnology–giving them the knowledge and materials they need to bring hands-on biotechnology projects into their classrooms and to teach their students about the societal implications of genetic engineering.

San Francisco State University has a decade-long track record in innovative science and math education. I am proud to say that we were quick to recognize the need to draw more women and more young people of color–the new faces of our increasingly diverse state–into these fields. Our MESA, Minority Engineering Program, Women in Engineering, Mission to College, and Young Engineers and Scientists programs are making science careers more attractive–and possible–for students of underrepresented minorities.

And in many other programs–too many to be discussed in this issue of the *Review*–we are finding new pathways to successful science and math education. A few brief instances suggest the range of our activities:

- The Math Leadership Program, whose summer institutes and monthly meetings

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help K-8 teachers feel more comfortable with mathematics and teach it more creatively.

- The Interactive Mathematics Project, which replaces the standard high school math curriculum with one based on large problems or ideas, rather than on smaller-scale concepts and skills.
- The SETI (Search for Extraterrestrial Intelligence) Curriculum Project, which is testing hands-on activities and experiments in a new series of guidebooks designed to keep student interest high.
- Our requirement–well in excess of certification requirements–that students preparing for elementary teaching careers take two specialized courses on teaching math and science.

The commitment to math, science and technology education is gaining ground, as more groups join forces. One new local coalition is bringing together 38 organizations and universities to create the Science Education Academy of the Bay Area. We are a participant, as are eight other universities, the NASA Ames Research Center, the Lawrence Hall of Science, the Stanford Linear Accelerator Center, and the U.S. Geological Survey.

Underlying all these creative efforts is the realization that scientific literacy for all citizens is more than a matter of national pride, more even than a matter of international competitiveness. It is a necessity, a demanding and rewarding element of a fully humanistic 21st century life.

I hope that you will find this issue of the *School of Education Review* both stimulating and encouraging.

A Word From The Dean

Henrietta S. Schwartz

The School of Education in cooperation with the School of Science and our corporate neighbor, Chevron, are pleased to sponsor this special issue of the Review devoted to Science Education. The topics covered are timely and challenging–the teaching and learning of how the world and the cosmos work, the organization and interaction of scientific themes and the central role of the teacher in achieving scientific literacy.

Science education has come a long way from the "Sorcerer's Apprentice" model of physics, through the medieval alchemist working in the castle dungeon transforming lead into gold, to the Gothic novel's notion of biology explicated so graphically in the experiments of Dr. Frankenstein, to the Victorian notions of biochemistry in the transformation of Dr. Jeckyl to Mr. Hyde. The early paradigms for studying the stars by connecting the dots to reveal Greek gods and goddesses has given way to the radio wave scanning of a SETI project. Some would claim that the romance and creativity have gone out of the study of science and they would be wrong as the articles in this unique issue of the *Review* reveal.

Science, like any creative endeavor is done by the curious, the passionate, the thinking and learning zealot. The working scientist adds to this combination, the ability to plan, organize, analyze, synthesize, work with others interested in the same questions and inspired by the same rewards–knowing why something works, and/or making something new that usually does not work at first.

In Western culture, the assumption was that all educated men would question the common assumptions of the society, observe natural phenomena with an eye to describing causes, origins and effects. No special curriculum was developed by the Academy or Aristotle or Pythagoras for the preparation of scientists. Students studied philosophy, mathematics, astrology/astronomy, religion/mythology and Greek or Latin. If a student had a particular bent for scientific inquiry, he was encouraged, perhaps apprenticed to a practicing astronomer and worked with other like interested students. Dialogue, discussion, demonstration, writing and lecture were the ways in which scientific information and discoveries were communicated.

Over time, education became more specialized and with the advent of the German model of universities and the Flexner Report of 1906 at Johns Hopkins University, the way in which American universities prepared scientific and medical and other professionals changed forever. Special science curricula have been developed at universities, distributed to the K-12 schools and alternately deified and decried by policy makers, educational critics and national commissions.

But as some wise person said, "We see farther than they did because we stand on their shoulders." Like education, science and scientific literacy is developmental and that means it takes time, talented professionals, eager and curious students and public support. And, as any good biologist knows, diversifying the species usually strengthens the new generations.

Until quite recently, serious science and sci-

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ence education was reserved for males, with rare exceptions like Nobel Laureates Marie Curie and Rosalyn Yalow whose passion and talent won them acceptance and opened the door a little to let other women in. The fact that half of the articles in this issue along with the special guest editor are not male is testimony to a much needed diversity among scientists and science educators.

The range of articles is wide. They flow from the set of articles on the national AAAS Project 2061 and the Scope, Sequence and Coordination Project of the National Science Teachers Association to the California Science Curriculum Framework and its influence on the preparation of K-12 teachers, to the more specific issues of assessment and special curricula and programs in technology, earth science and biotechnology. All of these efforts are aimed at improving science education by involving a wide array of scientists, teachers, the corporate world and the public in coordinated efforts. Science and technology are not just for the specialists; scientific and technical literacy are necessary tools for everyone living in the information age.

The goal of this issue of the *Review* is to contribute to knowledge in science education, to disseminate information about innovative programs which have proved successful in enhancing science education at various levels and at school sites, and to show how preservice and inservice education of teachers can contribute to national scientific literacy. No single organization or level can accomplish these goals alone. We must collaborate with our colleagues in the schools, in the state and at the national level to implement systemic reform in science and technology education. We must cooperate with our partners in business and industry to understand the scientific and technical needs of the workplace and with our scientists to balance environmental needs with economic health.

Above all, we must understand that the future of our society, indeed our planet, depends on an informed citizenry with a clear vision of how the physical world works and what humankind is doing to the planet. The simple handy-dandy guide to science–if it's green and it wriggles, it's biology; if it smells bad, it's chemistry; and, if it does not work, it's physics–just will not carry us into the 21st century. Life is more complex and we must prepare future generations to live in a scientifically and technologically interactive universe. It is to this purpose that this issue of the *Review* is dedicated.

Project 2061 From the National Perspective

F. James Rutherford

Project 2061 is a long-term reform initiative whose mission is nationwide science literacy. Being "long-term" may be the most distinguishing feature of the Project. Nevertheless, its national character is an important one. Part I of this paper notes some of the features of the Project that, collectively, reflect its national reach. Part II presents the Project's national strategy.

I. FEATURES

Science Literacy

Throughout this century, science education has confined itself mostly to the basic disciplines in the natural sciences–physics, chemistry, biology, and, more recently and more gingerly, geology and astronomy.[1] By contrast, science literacy encompasses a vastly larger territory, at least as defined in *Science for All Americans*, Project 2061's 1989 report (Oxford University Press, NYC).

Science literacy is concerned less with having students understand the disciplines, as such, than with having them understand the world through the eyes of science. Thus, science literacy draws on *all* of the natural sciences, the social sciences, and mathematics and statistics, as well as engineering and technology. Moreover, a person who is literate in science will be familiar with some of the important connections among these fields, with the scientific enterprise in general, and will have acquired some of the habits of mind associated with science, mathematics, and engineering. This literacy also involves the history, philosophy, and sociology of science (and math and technology).

Project 2061 has elected to concentrate on this common core of shared learning that will lead to national science literacy. But this commitment leads to a dilemma: the sweep of conceptual territory suggests more to be learned, and the inclusiveness of students suggests a lessening demand on learning. The Project 2061 solution is to *decrease* coverage in order to *increase* the time available for students to reach a useful and lasting understanding of the ideas encountered and to practice the needed skills in a variety of contexts.

Project 2061 is trying to establish a vision for achieving science literacy. *Science for All Americans* presents what all students should know and be able to do in science, mathematics, and technology by high school graduation as the main focus of all reform efforts at all levels–local, state, and national. *Science for all Americans* also articulates principles of learning and teaching that are part of this vision. Gradually, Project 2061 is having an effect: on the one hand, individual teachers and schools are adopting the *Science for All Americans* reform principles; on the other hand, federal agencies and some state departments of education are responding positively to its vision of science literacy.

Comprehensive

Project 2061's commitment to science literacy also brings a commitment to all students. In contrast, the goal of science competency is important for some students but not most. Literacy education is the threshold of understanding that all students will be expected to reach, though it does not preclude education beyond the threshold for those who wish it. As things stand now, students re-

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ceive a smattering of science, mathematics, and technology before high school, and then tracking takes over.

Few "vocational" and "general" students go beyond earth science, biology, and introductory algebra; few college-bound students study technology, and most of them avoid physics and math beyond advanced algebra. Almost none of these students have the opportunity to learn how science as a social enterprise works or to develop the critical-thinking skills characteristic of natural and social science, mathematics, and engineering.

Project 2061 is comprehensive in its focus on science literacy for all students, but it is comprehensive in other ways also. One of these ways is in its concern with the entire span of grades from kindergarten to high school graduation. Whereas most national projects concentrate, and reasonably so, on a fraction of the grades–elementary, or middle, or high school–Project 2061 operates on the belief that science literacy can be achieved for all students if and only if the entire school experience is reshaped.

Each of Project 2061's six school-district design teams is composed of 25 educators, including three principals selected to represent all grade levels, a diverse array of non-specialist elementary teachers and teachers of the usual school science and math subjects, as well as technology, social studies, and language arts teachers. Also, each team includes two members who have supervisory or curriculum responsibilities in their districts across all grades.

Long Term

Not surprisingly, it is fashionable now to cast national reform in terms of the year 2000, the end of the decade/century/ millennium, or 2001, the start of the next. No doubt, much can and ought to be accomplished by then, for we already know how to do better than we are doing. But significant, radical, and lasting transformation of education will take longer, much longer.

Believing that this is so, the American Association for the Advancement of Science (AAAS) designed and launched Project 2061 as a long-term undertaking, one to be measured in decades rather than years. Its approach is deliberate. More than three years were spent in studying past and current national reform efforts in science and mathematics education, examining the issues as expressed in the flood of national reports, interviewing concerned educators, scientists, policymakers, business and labor leaders, and considering a wide range of strategic possibilities.

That process was followed, beginning in 1985, with nearly four years' effort to spell out the learning outcomes in science literacy for all students. The result was *Science for all Americans*. The Project is now in the middle of this effort, which will also take at least four years, to:

(1) establish benchmarks for science literacy that can be used to estimate student progress toward the *Science for all Americans* goals;

(2) create curriculum models and a design system keyed to the models and extensive resources that would enable teachers to design new courses and curricula for achieving *Science for all Americans* goals; and

(3) prepare blueprints on how other aspects of the system must be changed to make the new content and approaches possible and effective.

Add all of that up and Project 2061 will have invested, by the end of the current phase of work, at least a decade in helping the nation get ready to undertake reform. Then, because there will still be so much more to do before the system is actually transformed, the AAAS intends to continue Project 2061 and its reform initiatives for as long as it takes–surely no less than another decade.

II. STRATEGY

In the context of educational reform, the designation "national" has several implications. One is reach. Programs to reform the schools may concentrate on one or more local school districts, one or more states, or on all schools in every state. Although the expressed goal of Project 2061 is national reform, that does not mean that it must simultaneously work with 50 states, 16,000 school districts, and 110,000 schools. The reach of reform influences, but does not altogether determine, what a reform strategy must be.

Science education reforms that are sponsored by national organizations, such as the AAAS or the National Science Teachers Association (NSTA), or mathematics education reforms, such as the National Council of Teachers of Mathematics (NCTM), are usually thought of as national, yet they may conduct projects of entirely local focus. There are also organizations, such as the Triangle Coalition (TC), and the National Center for Improving Science Education (NCISE), that were formed exclusively to promote nationwide reform.

But the "organization" that is most national, of course, is the federal government. By definition, it is supposed to serve national rather than parochial interests, even though that is often far from the case. But though federal implies national, the reverse is not true. The overall thrust of the National Science Foundation (NSF) may be national, but the efforts of its individual grantees may be quite local. With or without funding from federal agencies, a project may be national in terms of its reach and strategy.

If a reform initiative intends to help change the educational achievement of the nation's citizens, it is fair to ask how it intends to do so. In general, three dimensions exist to Project 2061's approach: it is systemic, inclusive, and utilitarian.

Systemic

Project 2061's approach to reform is systemic. In addition to concerning itself with all students and all grades, Project 2061 takes into account all aspects of the system of education–unlike most national reform projects that concentrate on one or another part of the system. The evidence is clear enough: you cannot bring about significant and lasting reforms in a complex system–and education is surely that–by fixing only part of it.

The Project operates from the assumption that many aspects of the educational system must be adjusted simultaneously for the changes to reinforce each other rather than being at odds. In order for all high school students to graduate literate in science, mathematics, and technology, the content of the curriculum must be changed along with teaching practices, the nature of the learning and teaching materials, the use of space and time in the schools, the policies governing education, and so forth. All of these changes must be in harmony if they are to make a difference.

Even as the Project works to design new K-12 curriculum models to achieve science literacy, it is reexamining every facet of the system: teacher education, assessment, the organization of schooling, policies, and more. To be sure, a steady stream of national studies and projects deal with these same issues, and Project 2061 is drawing on them; the difference is that Project 2061 is conducting its own studies simultaneously and within the context of developing alternative curriculum models to achieve the learning goals expressed in *Science for All Americans*.

What might the alternative be? Reforming every part of a system is a daunting prospect. Is there not some simpler way, some thing that would catalyze change? Over the years since World War II, different possibilities, often characterized in retrospect as failed panaceas, have been suggested and tried. "If only teachers were better, education would be better," one line of reasoning goes–leading to career ladders in some places, competency testing of teachers in others, or a few more days a year of inservice training.

In the 1960s, the catalytic solution was reform of content accompanied by teacher institutes. In the 1980s, reform consisted mostly of shifts (or controversy over proposed shifts) of the locus of authority in education. The argument for site-based management, for example, rests on the notion that, if only individual schools were freed from the stifling effect of bureaucratic regulation and put in the hands of the teachers, reform would follow.

Current debate on national reform centers on two such notions. One is choice: let students and parents select whatever schools they wish and the resulting "market" competition will lead to the survival of the best schools and, hence, to national reform. The other is testing: a national test (however configured) would define standards clearly, identify schools (or school districts or states) that fail to meet the standard, and lead to remediation or elimination as needed.

That description oversimplifies the arguments for these options and, indeed, all options ultimately may have a place in national reform. The point is that a range of approaches to national reform exists from the narrowly catalytic to the collaboratively systemic. The Project 2061 strategy is located near the latter end of that spectrum, because its designers believe that simple, single-aspect solutions cannot work on a national scale.

Inclusive

Should reform be top-down or bottom-up? The Project 2061 answer is "both" and, consequently, its strategy looks in both directions in order to be inclusive. An inclusive strategy is needed to be effective in a democratic society.

Those who favor bottom-up reform–which is generally referred to as "grass-roots"–argue that the only reforms to chance implementing effectively are those closest to the action, which is to say, in the classroom. It is unreasonable, however, to expect teachers and principals to undergo the difficulties of instituting reforms that they have had no hand in shaping. On the contrary, local educators–if given incentives, resources, and freedom–will deliver well-educated graduates.

Top-down approaches–which are rarely called that–take the position that, without strong guidance, local initiatives tend to go in any and all directions. The result may be improved education here and there but not everywhere. Practically, this approach calls for national or state standards, national or state assessments, or state curriculum guidelines and regulations. This top-down approach also shows up in the priorities set by federal, state, and private foundation funding. The relatively greater availability of support for local undertakings are for those that come closest to the preferences of federal and national agencies.

Project 2061 takes the view that bottom-up and top-down approaches are both essential to significant, sustained national reform in science, mathematics, and technology education (and other domains as well). Project 2061 intends to influence "top-down" initiatives by contributing to their formulation. This strategy means collaborating with other organizations and reform groups in the creation of national standards, the design of assessment instruments and procedures, and the formulation of funding policies. It also includes working with state groups to help shape state curriculum guidelines, state assessments, and state regulations.

The Project does not see its job as one of deciding what kinds of initiatives the federal or state governments should undertake, but rather of assisting those initiatives that are compatible with its long-term mission for science literacy. This 2061 strategy leads to collaborating with other like-minded national projects, many of which are funded primarily by national foundations instead of government agencies.

Utilitarian

Project 2061 is utilitarian in its recognition of what is needed to get the job of reform done. If teachers and administrators working together at the school or district level are to reshape science, mathematics, and technology education in the light of *Science for All Americans*, then they will need resource tools for doing so. In general, it is unrealistic to expect teachers to create powerful new curricula by themselves and without resources. Project 2061 is not creating curricula; it is designing a coordinated set of tools that will enable educators to do so. These same tools will help materials developers, test developers, and teacher educators.

Project 2061's reform "tools" are now under development by practicing educators backed up by university and other consultants. Because these tools are emerging from the actual learning environment in a variety of school settings, the hope is that they will be both forward-looking and practical and that they will enable other teachers to play a creative role. *Science for All Americans* is a reform tool that will soon be backed-up by the following:

> *Benchmarks*. Standards for science literacy–what Project 2061 call benchmarks–will describe how educators can judge the progress students make toward the learning goals presented in *Science for All Americans*. Currently, benchmarks are being developed to suggest what students should know and be able to do by grades 2, 5, 8, and 12. They will also indicate the character and contexts for such progress.
>
> *Curriculum Models*. Four different approaches to the design of the K-12 common core of shared learning will be outlined. Enough detail will be offered for teachers to construct a curriculum that, while incorporating their own prefer-

ences and taking into account local circumstances, will eventually produce science literate graduates. These alternative curriculum models will be accompanied by suggested ways and means for reforming the curriculum and making other needed changes in order to use the models effectively.

Blueprints for Reform. These studies will examine at least eleven different aspects of the education system–teacher education, materials, assessment, policies, etc.–in the light of *Science for all Americans* and the 2061 curriculum models. The blueprints will result in concrete recommendations for bringing about systemic reform at the school, district, state, and national levels.

Design System. Searching out the best learning/teaching materials, summarizing their uses, connecting them to discrete locations in the curriculum, and keeping them up to date is enormously time-consuming and labor-intensive. Add to this the need to include outstanding assessment resources, pertinent research studies, and information on where the various resources have been field tested or are in current use. Project 2061 models also need to be tied in to such information along with the rationales, conceptual maps, content inventories, and other directly related matters. Hence, the Project is undertaking to develop a computer based curriculum-design and resource system that will make all such information *easily* available to educators at the local level.

How effective will this three-sided strategy of Project 2061 turn out to be in bringing about national reform? It is much too early to tell. It is clear, however, that by working with others it can contribute significantly to building a critical mass of thoughtful and sustained reform activity at every level. If we work together, science literacy can become a reality in the United States; if we do not, it will not.

Endnote

1. Go back to the Middle Ages and you will find that astronomy and geometry ruled the scientific side of the curriculum roost.

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Project 2061 - The California Perspective

Philip D. Gay

California has provided a receptive environment for Project 2061 for many of its own reforms in science education parallel those of the AAAS' initiative. In addition, Californians were involved in the Phase I activities of Project 2061. James Rutherford, Director of Project 2061, met with the developers of the 1990 "California Science Framework," and the California Post-secondary Education Commission supported the collaboration between the University of California and California State University systems and the San Diego and San Francisco schools on Project 2061 goals. These and other interactions among state participants involved in the reform of science education have made California a unique site for Project 2061 efforts.

Conventional wisdom suggests that "you can lead a horse to water, but you can't make it drink." Unless, of course, the horse is thirsty *and* the water is good! Many life situations mirror this condition.

In education, many of us–teachers, school administrators, school board members, and parents–often forget the value of attracting young people, rather than forcing them, into the education enterprise. It may well be that only when the entire population becomes "thirsty enough to drink" (truly curious) and finds "invigorating water" (relevant experiences) that this nation will achieve the level of literacy that is our potential for the twenty-first century.

Restless Californians tend to ask questions about their education system more often than those in other parts of the country. This tradition of asking and analyzing may underlie the location of much scientific research and many high-tech industries in this state. Within California's education community, support is current and ongoing for the development of curriculum frameworks, assessment devices, teacher credential requirements, etc. Such policies and practices are revised periodically to reflect the state's evolving views of education. Thus, Project 2061, the reform initiative for science literacy from the American Association for the Advancement of Science (AAAS), stepped into a receptive environment in California.

Becoming Aware of Project 2061

The California K-12 science education community first learned of Project 2061 in early 1986 at the California Science Framework Addendum Implementation Conference held at California State University, Long Beach (CSULB). Many of us were energized by the possibilities of this long-term reform initiative and immediately wanted to become a part of the process.

Involvement didn't follow right away for K-12 school personnel, but California was fortunate that two of Project 2061's Phase I panel members of scientists and education experts were from California. The Mathematics Panel was built upon expertise at the University of California at Berkeley (UCB) and included participants from several other prestigious higher education and research institutions in the state. Similarly, the Biological Sciences Panel built upon the strong faculty at the University of California at San Diego (UCSD) and included participants from San Diego State University (SDSU) as well.

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From the perspective of California's K-12 science educators, however, little of that Phase I process of Project 2061 filtered down until May 1988. By that time, the revision cycle of the state's curriculum frameworks in various subject areas had come around to science again. Dr. Elizabeth Stage, then at Lawrence Hall of Science at UCB, chaired the science curriculum revision committee. The committee, composed of 16 representatives from the community and from the K-12 system and higher education, began its work January 1988.

Dr. Stage and Thomas Sachse, Science Coordinator in the California Department of Education, collaborated in the revision process. They had the foresight to invite Dr. F. James Rutherford, chief education officer at the American Association for the Advancement of Science (AAAS), to share his draft of what is now known as *Science for All Americans*, the Phase I report of Project 2061. As Director of Project 2061, Dr. Rutherford's presentation that May day was memorable.

Members of the revision committee recall the intensity with which they heard Project 2061's message. The committee's thinking had come to consensus in the four or five meetings they had held previous to that time. The remarkable strides they had made were in the very directions that Project 2061 was suggesting! For example, the committee had studied the meaning and usefulness of cross-disciplinary themes and had developed a tentative list of six themes for consideration. Imagine our delight when we heard that the authors of *Science for all Americans* also had a list of themes, built on a similar rationale, and using some of the same terms! Also, two draft chapters in *Science for all Americans*–the "Nature of Science" and "Habits of Mind"–were remarkably similar to specific discussions of the committee. This validation of California's initial direction on the science curriculum work in progress was invigorating and useful to the revision committee.

An Example of Parallel Development

In February 1989, *Science for All Americans* was published. In late 1990, the *Science Framework for California Public Schools* was adopted by the California State Board of Education. Readers who compare both documents will immediately notice that their scope is different. The California document, not surprisingly, made its statement specifically for the K-12 science curriculum for this state. *Science for all Americans* included mathematics and the social sciences as part of a coherent picture of what *all* science and technology literate citizens of the twenty-first century ought to know.

Even with this difference of scope, however, specific approaches were held in common. The concept of "less is more"–fewer isolated facts and more conceptual depth–is a clear expectation in both documents. The "interconnectedness" among and between disciplines–similar to the curriculum connections emphasized in *Science for all Americans*–is also a key component of the *California Science Framework*.

In particular, the use of themes, such as patterns or scale, in the two documents suggested how this might be accomplished. The California science curriculum revision committee had developed its tentative list of useful themes to link content across disciplines. After they heard Dr. Rutherford's draft list of themes for *Science for all Americans*, the committee put both lists side by side and came upon a new list. That list, with accompanying explanations, became Chapter 2 in the *California Science Framework* adopted in 1990.

The California committee felt strongly about the value of these themes in helping students obtain a more coherent understanding of science content and thought processes. Thus, the committee placed them before the content analysis statements in Chapters 3, 4, and 5. That sequence was intended to communicate its priority and value for California science educators.

The authors of *Science for all Americans* placed their "theme" presentation in Chapter 11 of 12 chapters. It will be interesting to review the alternative curriculum models being designed in Phase II of Project 2061 and learn how its six school-based design teams used the "theme" approach to achieve their K-12 curriculum models.

On-going Events in California

Another outcome of May, 1988, was the awareness that one or more major California school districts were being considered as R&D sites for Project 2061's Phase II. During the discussions that ensued over the next several months, San Francisco Unified School District and San Diego City

Schools were selected from around the nation as two of the six sites. They were to form 25-person teams of educators for the two and one-half year development period that began in April 1989. Other representatives, including a teacher from the Fresno area in California's central valley, served on a national advisory panel that conve d several times.

One of the criteria involved in the selection of sites was the proximity to knowledgeable and interested university resources. State leaders from the California Department of Education were also involved, including Tom Sachse and Bill Honig, State Superintendent of Schools, and Linda Barton-White from the California Postsecondary Education Commission. They alerted both the San Francisco and San Diego sites that the current cycle of requests for proposals for federal funding to support K-12/Higher Education collaborative efforts included a category that might support the goals of Project 2061.

As a result, two first-round proposals were submitted: one from northern California to support the work of the State University and the University of California campuses closest to the San Francisco Unified School District's 2061 team; and one from southern California to support the similar campuses near the San Diego City Schools' 2061 team. The Commission's Review Panel responded by requesting one joint proposal for the entire state; thus was born the "California Project 2061 Collaborative." It was funded, and operations ran from April 1, 1989, to June 30, 1992.

The structure and process of the California Project 2061 Collaborative reflected California's perspective on Project 2061. The six participating institutions and their liaisons to the project were: San Francisco Unified School District (Bernard Farges) with their neighbors, San Francisco State University (SFSU) (Dr. Kathleen O'Sullivan) and University of California at Berkeley's (UCB) Lawrence Hall of Science (Tim Aaronson); and San Diego City Schools (Phil Gay) with their neighbors, San Diego State University (SDSU) (Dr. James Mason) and University of California at San Diego (UCSD) (Dr. Randall Souviney).

The four University liaisons participated regularly in meetings of the development teams, both at the local and national levels. They were especially helpful in identifying experts on their respective campuses to provide input, review drafts, and participate collaboratively in small working groups from each team.

Joint meetings of the two teams were one of the most useful activities resulting from the California Project 2061 Collaborative. The first of these, held at a residential retreat center in Menlo Park, California, in March 1990, gave the San Diego team members the opportunity to work with several new resource persons from the northern California universities and San Francisco area K-12 schools. It also allowed for continuation of discussions begun the previous summer, when all 150 members of the six site teams spent four weeks working together at the University of Colorado in Boulder.

The second joint meeting brought the San Francisco team members to Southern California the next fall, September 1990, for a similar three day residential retreat away from telephones and other professional and personal responsibilities. By this time the teams had experienced another collective four week summer session, this time at the University of Wisconsin in Madison, and were well along in the process of building their curriculum models.

Planning discussions at these summer work sessions mirrored a concern similarly expressed at the national level: would meetings of this sort, which enabled such close contact and interaction among teams, cause their efforts to converge and become too similar–i.e., no longer unique–than might have been the case had they continued to work separately? In fact, this did not happen.

What did happen was clarification and evolution of each team's perspective as a result of meeting together and sharing ideas. The perspectives already under development at each site–about which approaches would best ensure that future high school graduates achieve the learning outcomes in *Science for all Americans*–were strengthened rather than diluted. Convincing evidence of this was reflected in the curriculum models that each site team submitted to the national project.

Other Concurrent Influences

The activities of California's two Project 2061 teams have had other indirect influences statewide. One was the "100 Schools Project," funded by the

National Science Foundation (NSF) and coordinated by the state, to develop and implement the grade 6-12 ideas of the National Science Teachers Association's (NSTA) "Scope, Sequence and Coordination" (SS&C) project. Because the NSTA's SS&C project adopted *Science for all Americans* as its statement of desired outcomes, the 100 Schools Project has been "looking over its shoulder" at the California Project 2061 Collaborative as well as sharing ideas in a variety of formal and informal ways. A few of the Project 2061 team members in California teach in schools that received 100 Schools grants and, therefore, serve as direct links. These contacts continue, and their value will become more apparent in the years ahead. Similar formal and informal contacts have also occurred:

The California Science Implementation Network (CSIN), the state's K-6 approximate equivalent of the 100 Schools project, had a science teacher from San Francisco Unified School District as one of its early participants. That teacher later became the co-leader for the San Francisco 2061 team for the first half of the Project activities.

On another occasion, a San Diego County CSIN training session was held on the same campus as the office of the San Diego Project 2061 team. As a result, productive conversations occurred between the directors of both projects.

On numerous occasions, CSIN and Project 2061 participants have attended each other's sessions at regional science education conferences in various parts of California.

The California Assessment Program (CAP), particularly the science assessment component, has had frequent contact with Project 2061 activities. AAAS invited CAP representative, Kathleen Comfort, to present at their National School Science Forum on Assessment in October, 1989. She also worked with a national task group on assessment, which included representatives from all six 2061 teams, during the summer work session at the University of Wisconsin, in July, 1990.

In the last two years, California's Commission on Teacher Credentialing (CTC) has convened study panels to make recommendations for changes in credential requirements. This author served on the physical science panel and interpreted the Project 2061 vision on several occasions during that process.

Many of the California Science Teachers Association's (CSTA) regional associations have held conferences since the California Project 2061 Collaborative began and sessions by members of both the San Francisco and the San Diego teams have been conducted at these conferences. These sessions have not only been opportunities for expanding general awareness of Project 2061's reform premises to the entire science education community in California, but have also provided the R&D teams with input for their ongoing development work.

The above list of interactions among Project 2061 and other education reform activities in California is undoubtedly incomplete and misses other important links. The important message, however, is that Project 2061 has already had important impact and long-term effects on the science education community in California.

A Moment in Time

Perhaps one of the most significant outcomes to date is the useful dialogue initiated between K-12 educators and higher education professionals. An expanding awareness exists that higher education must respond to these new ways of preparing science and technology literate high school graduates in two specific areas: most immediately, in the preparation of teacher candidates who can grasp the new vision for science literacy and implement it in appropriate ways; and, in the not-too-distant future, be prepared in K-12 settings to greet students who have learned how to learn in entirely new ways.

Paul DeHart Hurd, Professor Emeritus of Science Education at Stanford University, joined with the assembled California team members at both the Northern California and Southern California joint retreats mentioned previously. At the second retreat, he listened to many small group sessions for two days and then made suggestions during the after-dinner joint session. His challenge to the group was that education had not really changed very much in the last 300 years, but that this project was–and is–an opportunity to rethink how education is accomplished and to suggest what ways will lead us into the world of the future.

This echo of Dr. Rutherford's initial instructions in 1989 to California 2061 teams–that we "wipe the slate clean" and find new and better ways of accomplishing our desired goals–continues as a beacon before us. We have engaged in an on-going, long-term, do-it-while-we're-in-motion process. Can we step out of our old-paradigm and find the new ways we need? The potential for California students lies with Project 2061.

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Project 2061 From the San Francisco Unified School District's Perspective

Bernard Farges

San Francisco Project 2061 is one of six national sites to participate in phase II of Project 2061 and translate the goals in Science for All Americans (AAAS, 1989) into a K-12 curriculum model. The San Francisco model is currently under review and four school sites in the San Francisco Unified School District are presently preparing for its implementation starting September 1993.

Shifting The Paradigm

As we shift from an industrial society to an information society, *the expectations of our citizens have changed.* Production, access, and utilization of information have become the keys to personal, social, and global well-being, thus making it imperative to *redefine what we value* with respect to the outcomes of schooling. As it has been pointed out, "Those who would treat schooling as designed to educate students on all important subjects are doomed to encounter the futility that faced Sisyphus: the boulder of essential content can only come thundering down the (growing) hill of knowledge" (Wiggins, 1989).

The basic question the educational community must address is less "how much should each student know?" than "how well should each student understand?" The emphasis must be shifted from quantity to quality, from thought mastery to thoughtfulness, from learning *of* the objective to learning *from* the objective, or, in other words, from "an education for a learned spectator of others' work" to "an education for an apprentice performer" (Wiggins, 1992). Students must be put in control of their own thinking and actions. They must be part of the process of arriving at the major decisions that affect their lives. As we move from representative democracy to participatory democracy, it is essential that students feel they have "ownership" in decisions if they are to support them with any enthusiasm.

Developing and sustaining a shared vision of the results we want from the educational process is crucial since what we, as educators, see is ultimately what students get. And those results will be measured not by what we teach but by what the students will actually end up learning.

San Francisco's Curriculum Model

A brief history

The San Francisco Unified School District is one of six national sites selected by Project 2061 of the American Association for the Advancement of Science (AAAS). Each site was to translate the goals in *Science for All Americans* (AAAS, 1989), the Project's 1989 report, into a K-12 curriculum model. This set of alternative curriculum models is intended to be one of Project 2061's tools for reforming science, mathematics, and technology education.

Formed during the Spring of 1989, the San Francisco team included five elementary school teachers, five middle school teachers, ten high school teachers (science, mathematics, social studies, and technology), three principals (elementary, middle, and high school), and two curriculum specialists (science and mathematics). This ethnically diverse group of educators (three Chinese, one Japanese, one Vietnamese, six Latinos, three Afri-

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can-Americans, eleven white) was balanced both in gender and length of teaching experience.

Over the two-year period 1989-1991, the team members worked in committees, cooperating across all grade levels and subject areas, to produce the San Francisco draft curriculum model. During those academic years, the team met three days a month to design its curriculum model. Each whole-day meeting was run by three rotating team members, functioning as a facilitator, a recorder, and a reflector. The team worked closely with faculty at San Francisco State University and the Lawrence Hall of Science at the University of California at Berkeley.

During the two years in which the draft curriculum model was being designed, team members refined their understanding of the learning outcomes in *Science for All Americans* (AAAS, 1989). They explored new ways of teaching science at retreats, conferences, and summer work sessions. The exchange of ideas among team members, locally and nationally, was also facilitated with an electronic computer network which linked all six sites and the Project 2061 headquarters.

The San Francisco draft curriculum model was presented by the San Francisco team at the 1991 summer work session organized by AAAS in Seattle, Washington. For the San Francisco team, the main outcome of the summer was its decision to design a curriculum model whose learning experiences would integrate the natural sciences, mathematics, and technology as well as the social sciences and the humanities.

The San Francisco team's draft model is currently under review nationally and within its school district and state. Revisions are expected. San Francisco Project 2061 plans to submit its final draft to AAAS by the end of June, 1993. At the same time, the San Francisco team is preparing for the implementation of its model at selected sites throughout the district starting September, 1993.

Profile

The San Francisco model is a set of recommendations addressing the needs of the multicultural, multilingual, and transient student population of San Francisco with respect to learning and teaching the natural and social sciences, mathematics, technology, and the humanities. The model challenges all students to address real environmental and social issues of local as well as global scope. Within multi-age groups, the students are given many opportunities for choice. They actively engage in learning experiences that emphasize investigating, problem-solving, and creating. By bringing the community into the school and taking the students into the community, the San Francisco model empowers students to take action to make meaningful differences in their lives and the world.

Figure 1

The San Francisco Curriculum Model

Philosophy

The most reliable way to prepare all of our students to lead personally fulfilling and socially responsible lives is to help them understand the present, *their* present. With the rapid growth of scientific knowledge and technological power, science literacy can enable students to view the world and themselves from many perspectives and, thus, become informed and participating members in a democratic, multicultural society.

As unique and whole individuals, students bring different needs, experiences, knowledge, and interests to the classroom. As a result, they develop and learn in different areas, at different rates, and in different ways. Students learn by actively constructing meaning for themselves from experiences that are purposeful and personal. They come to new understandings by weighing new information against their previous understanding, thinking about and working through discrepancies. If students are enabled to develop their different kinds of intelligences, they can maximize their personal, social, intellectual, and physical potentials. Each student must have equal chances to experience success, to celebrate one's uniqueness, and to make a difference in this world.

Focus of learning

The San Francisco model proposes to organize the curriculum around learning experiences in the form of *challenges* relating to survival as well as to the quality of life. Each challenge consists of a worthy task that engages the students in *investigating and responding to issues* (emphasizing challenges of belief), in *solving problems* (emphasizing challenges to action), and/or in *creating products* (emphasizing challenges to imagination).

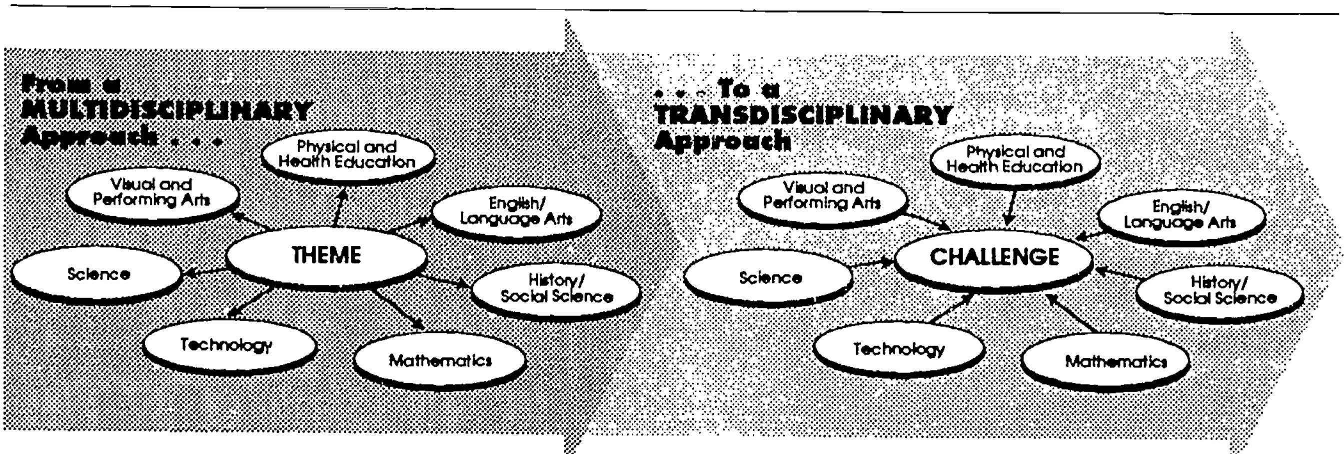
Learning experiences are differentiated from learning activities: they have a grander purpose and a larger scope; they take a longer time to complete; they are less content-specific and less task-specific; and they involve both critical and creative thinking skills. Each learning experience requires students to define the task at hand, set goals, establish criteria, research and gather information, activate prior knowledge, generate additional ideas and questions, organize, analyze, and integrate all this information. In the process, they are to construct new meanings, complete the tasks, share the products with an audience, and evaluate the outcomes of the learning experience in terms of process and product.

When important ideas are embedded in environmental and social issues, in problems of local and global concern, or in creative products, they extend the boundaries of any discipline. As a result, the model's learning experiences emphasize the interconnections between and among subject areas. Thus, the San Francisco models calls for *a curriculum integrated across all disciplines.*

This integrated approach differs from multidisciplinary approaches in that the curriculum model is integrated *from the student's point of view:* the students bring in knowledge and skills from various disciplines as they address a single challenge meaningful to them, rather than "do" single discipline-related activities that are organized around a topic or theme. For example, the students use data analysis to learn about the implications of our increasing world population, as opposed to using world population data in order to have a reason to learn data analysis. In our transdisciplinary approach, the lines of inquiry are prompted by the main challenge (Figure 2). The resulting learning experience consists of a set of activities "organically" connected by a sense of purpose rather than by a string of disjointed, conceptually juxtaposed, and discipline-driven activities. As a result, students experience learning as a whole, rather than through fragmented disciplinary views.

Figure 2

Focus of Learning: Lines of Inquiry



Distribution of content

The content of the curriculum is organized into four areas of study: *Self, Communities, Biomes,* and *Universe.* These four *systemic organizers* are interrelated but have a primary focus on the individual, society, the natural living environment, or the physical universe.

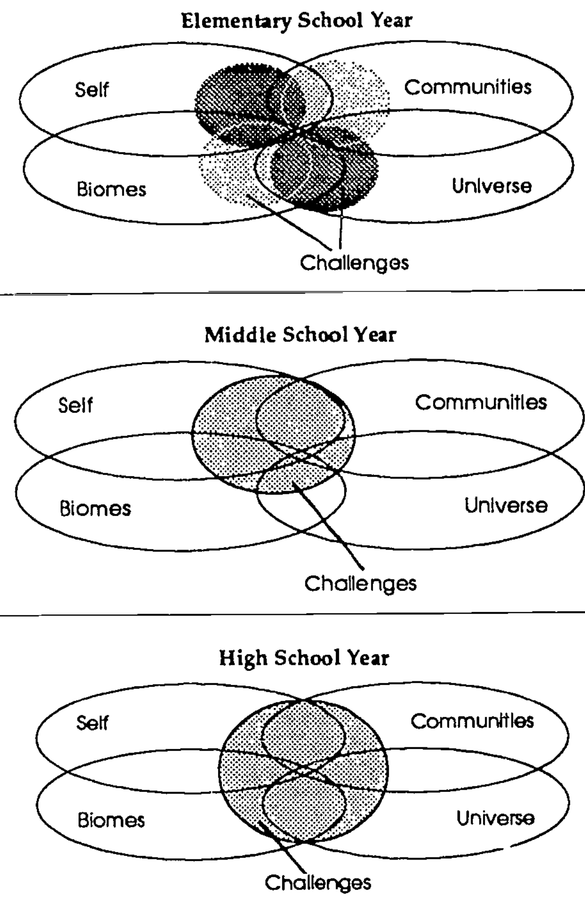
At the elementary school level, the degree of complexity is appropriate to the students' cognitive development. Each learning experience is contained within one of the four systemic organizers; however, relevant connections are made to other systemic organizers when appropriate. The exploration of *Self* centers around themes of the body and health, personal identity, family, and personal enrichment. Challenges related to *Communities* focus on the San Francisco Bay Area, including its environment, heritage, personalities, and current events, as well as contrasts with other communities in the world. The *Biomes* study focuses on the physical, biological, and human factors affecting a specific biome of the Earth, and then is compared with the Bay Area ecosystem. The *Universe* incorporates key concepts and ideas from all the physical, biological, mathematical, and social sciences through a focus on the physical universe.

At the middle school level, early adolescents are undergoing dramatic physical, social, emotional, and intellectual growth, and are especially vulnerable. It is during that time that they establish habits and values that have critical and life-long influence. Young adolescents ask the most profound questions: Who am I? What can I be? What should I be? What should I do? To help students respond to these questions effectively, learning experiences may focus primarily on *Self.* Because the personal concerns of early adolescents and the larger issues that face our world are frequently micro or macro versions of each other, learning experiences may also focus on the intersection of *Self* and *Communities* (Figure 3):

> Such, for example, is the relationship between developing personal self-esteem and the search for collective efficacy among cultures, between forming peer group connections and pursuing global interdependence, between the status differentiations among peers and the defining conditions of socioeconomic class distinctions, between personal physical wellness and environmental improvement, between understanding personal developmental changes and conceptualizing a society and world in transition, and between frustration over adult authority and struggles for human and civil rights. (Beane, 1990, p. 40)

Figure 3

Types of Learning Experiences



Community outreach including community service, "career shadowing," and numerous field trips move the students out of the classroom and expand their awareness of opportunities and possibilities that can impact their current and future educational and career choices. Challenges related to earthquakes, a gold rush simulation, and the

San Francisco Estuary: Its use, abuse, and recovery, are of special interest to the San Francisco area and lend themselves to a natural integration of many disciplines.

At the high school level, students choose from a menu of interdisciplinary experiences that address the learning outcomes of *Science for All Americans* (AAAS, 1989) and that cut across the four systemic organizers. Students' choices are based on issues, problems, creations, or challenges with global ramifications rather than on single subject courses. Projects, investigations, case studies, simulations, and seminars are utilized. At this level, initial exemplars include Space Exploration, Water Use in the Bay Area, and The Increasing World Population. In addition, "background" classes are offered as an opportunity to investigate and solve problems directly related to either mathematics or science. These classes ensure that students enhance and extend key ideas and skills in each of these disciplines and further consolidate their understanding of the major conceptual systems.

Character of teaching and learning

In the San Francisco model, curriculum, instruction, and assessment are both student-centered and challenge-centered. Students learn by being actively engaged in purposeful and personally meaningful interdisciplinary learning experiences that are conceptually, contextually, and experientially rich. They move towards the realization of their full potentials at their own rate and participate in these learning experiences based on their interests and academic needs. Emphasis is on understanding one's own thinking and how to direct it. Self-assessment and the development of metacognitive skills are integral parts of the curriculum.

Teachers are the architects and facilitators of the learning process. They promote a spirit of healthy questioning rooted within the range of students' perception, understanding, and knowledge. They involve students in *planning, in doing,* and *finding out* things, in *sharing* what they have learned with an audience, and in *assessing* their own learning. Teachers model and stress effective oral and written communication, while deemphasizing the memorization of technical vocabulary. They teach for understanding, realizing that understanding anything is never absolute and takes many forms.

Teachers build on success and strive to make all students aware of their progress as they learn. They encourage and reward curiosity, creativity, open-mindedness, and aesthetic responses. They present ideas in historical context and ensure that students become aware of the significant contributions throughout history of women, minorities, and people with disabilities. Teachers frequently use a team approach so that students experience sharing responsibility for learning with each other. They exploit the resources of the larger community and involve parents and other concerned adults in the delivery of the curriculum. In this model, the teacher is an architect of instruction, a facilitator of learning, a provider of resources, a researcher, a guide, a member of an audience, and most importantly, a model learner.

Time configuration

The design of this model is intended to address the personal, social, academic, and physical needs of all students as well as to maximize their opportunities for choice. The K-12 sequence of studies consists largely of a set of interdisciplinary learning experiences that engage students during extended periods of time, rather than specific subjects and courses addressed during fifty-minute periods. Time is allocated, however, for more in-depth study of some key concepts in the natural and social sciences, mathematics, and the humanities.

At the elementary school level, the daily schedule for each student includes family time, discovery time, physical activity time, and personal time. Families are heterogeneous and multiage groups designed to offer each child emotional stability and continuity over several years. They meet at the beginning and the end of the school day so that students may plan and assess their day as well as deal with personal and social problems. Students concentrate on "content" learning through choices during discovery time, either by exploring in the context of learning activities or by focusing on a learning experience. Physical activities including psychomotor exercises, multicultural dances, and games are also integrated into the curriculum. Finally, personal time allows students to explore and discover their own interests, hobbies, avocations, and creative forces.

At the middle school level, the school day consists of family time (used in the same manner as at the elementary level), project time, a core curriculum block, and physical activity time. Project time provides for interdisciplinary learning experiences while the core curriculum block focuses on more discipline-oriented concepts and skills. A culminating learning experience brings together entire units of study three times a year.

At both the elementary and middle school levels, an Individual Student Study Team is assigned to each student. It includes the student, the teacher(s), the parents/guardians/advocates, and possibly a social worker/translator. This team meets at least quarterly to ensure that each student's emotional, social, academic, and physical needs are met. The team makes recommendations for placement based on the student's academic, social, and personal progress. Socialization and problem-solving of a personal or collective nature take place in "family" groups at the beginning and end of each school day.

At the high school level, students have extended blocks of uninterrupted time during the day, the week, and/or the year to carry on such tasks as projects, model building, laboratory work, and field studies. It may be appropriate to spend an entire day, week, or longer period of time conducting a project away from the school site, thereby maximizing community interacton. "wild card seminars" modeled after university "brown bag" lunches are offered periodically for students to attend and listen to various speakers based solely on their own interest and curiosity for learning.

A specific meeting time is set aside at the beginning and end of each school day to allow for the same group of students of the same age to work together with teachers throughout the high school years to address their personal, social, academic, and physical needs.

Assessment

The purpose of assessment is to *improve learning*. Assessment is intimately linked to both curriculum and instruction. Meaningful assessment of students' progress and authentic achievement is of critical importance in the educational process. It colors the entire psychological setting of a student's education and can decide the fate of innovations in curriculum and instruction.

One must assess what one values most. The goal of authentic assessment is not just to document competence. It is to provide the students with meaningful and high-quality tasks that have personal, utilitarian, and/or aesthetic value. Assessment measures the ability of students to construct and apply rather than reproduce knowledge. In San Francisco's model, students participate in developing standards for quality work and are given multiple models of what is expected from them.

The tools for assessment include the following:

- *Portfolios* are collected works of each student which both document progress and represent his/her best efforts and accomplishments. Their purpose is to provide evidence of reaching the benchmarks as described in the learning experiences, or other goals selected by the Individual Student Study Team or the teachers and the student. Portfolios provide diagnostic, formative, and summative assessments of each student's work. They may include *student products* such as written responses to open-ended questions, journals, videotapes and audiotapes of students' individual and collective performances and presentations, interviews and exhibitions, investigation reports, simulations, pictures of physical constructions of models, and artistic creations. They may also include documentation of student work in the form of letters from supervisors from a community project. A critical component of a portfolio is the element of a student's reflection. The value and purpose of each selected entry is documented by the student.
- *Substantive dialogue* is the engagement of the student in meaningful discourse with another. The ability to express opinions, exchange ideas, and persuade the listener are conversational skills which must be evaluated through actual dialogue. This type of evaluation gives the student meaningful and immediate feedback, and gives the teacher insight into the student's thinking and level of cognition.

- *Projects* demonstrate the student's depth of understanding and competence in many skills. Criteria for evaluation must be set by students and teachers during the initial phase of the project.
- *Cooperative performance* evaluates the product of a collective effort as well as the behavioral aspects of group participation. The ability of an individual to function as a team member is recognized as a valuable skill and a necessary component of the schooling process.

Equity

This model emphasizes the need to develop a relationship of trust among students, teachers, families, administrators, business people, and the community in general, i.e., equity. Equity involves a sensitivity to people with different languages, cultures, belief systems, lifestyles, learning styles, and disabilities. To foster equity, each student's home language and culture must be incorporated into the school program. Positive role models are also essential for students. Teachers, community leaders, scientists, and other professionals of all sexes, sexual orientations, races, abilities, and languages can be brought into the learning context. School libraries must maintain collections in languages of the site population.

Partnerships

Finally, the San Francisco draft model also builds partnerships between the scientific community and the schools. These partnerships can provide students with additional learning in practical ways. Further connections between the curriculum and the scientific enterprise and between science and the real world are available through active involvement in local regulatory agencies and advocacy groups.

Implications for Change

In the area of assessment, this model requires *state and national support*. The state needs to provide many opportunities and support systems to inservice teachers from all subject areas on *authentic assessment*. Structures to open a dialogue between the K-12 program and assessment standards and *institutions of higher education* need to be formed to coordinate admission standards at the university level. At the national level, a need exists to align current nationally funded assessment projects with Project 2061 benchmerks for science literacy as well as to develop additional programs to secure funding for projects focusing on authentic assessment.

To serve the interest of their students, *teachers* need to be more than knowledgeable in their subject matter. Teachers must have an appreciation of the students' diverse cultures, the social factors affecting their lives, and other issues and concerns relevant to students. Teachers must have an understanding of language development strategies and of a variety of learning styles and intelligences. They must move beyond the limits of the classroom and the development of discrete daily lesson plans. They need to view the community as the classroom and use its resources to facilitate in-depth learning. It is critical for the *institutions of higher education* to provide preservice reflecting those envisioned changes. Teachers also need adequate time collectively to plan the curriculum within and across disciplines, to maintain the range of materials and supplies necessary to manage diverse learning experiences and to assess students' progress in learning.

It is critical to include *library media specialists* as partners in the learning process. As information specialists, teachers, and instructional consultants, they help students develop lifelong learning habits, thinking skills, and the ability to use information effectively. By offering both traditional resources and new technologies as teaching and learning tools, library media specialists make a major contribution toward achievement of literacy, especially information literacy.

To accommodate different learning styles, a variety of *teaching materials and technologies* are needed, such as manipulative tools, videos, interactive videodisc systems, and microcomputers. Microcomputers link teachers to other teachers, students, administrators, online resources, and central district personnel via cables, telephone lines, and satellite communication systems.

To integrate the learning experiences and foster a community structure, the *organization of schools* in both time and space must be considered. This model proposes a K-12 comprehensive school that is non-graded both physically and academically.

A year-round school with an extended daily calendar is also proposed to meet the needs of children who have limited options for after school activity and extended education. Community support and linkages are key factors to be considered in the organization of schooling.

To affect a change in curriculum and instruction, this curriculum model calls for a radical change in *educational policies* that can obtain full understanding by educators, parents, constituency organizations, the community, and policymakers. Such policies should promote risk-taking, provide resources and time, and respect the intellectual capacity of educators to break old paradigms and fashion an educational program for the 21st century.

To understand the effects of urban environments and cultural diversity on teaching and learning, this model would profit from increased *educational research*. An immediate focus of research is the careful monitoring, documentation, and assessment of school-site implementation. Outside support, both personnel and financial, will be necessary. Those directly involved, including teachers and students, should be co-investigators and data sources. Research partnerships between the school community and the research community are thus essential to the understanding and implementation of this model.

Moving Toward the Implementation of the San Francisco Model

Four school sites in the San Francisco Unified School District are presently preparing for the implementation of the San Francisco curriculum model starting September, 1993. They include Hawthorne Elementary School (K-5), San Francisco Community (K-8), Horace Mann Academic School (6-8), and Mission High School (9-12). Most of these sites have already started a partial implementation of learning experiences developed in the past two years. The preliminary observations of their impact on students' learning will guide the beginning of the implementation in September, 1993.

Taking Advantage of the Present

Poor student performance, adult scientific (and other) illiteracy, America's declining economic competitiveness, and future shortages of scientists and engineers are compelling reasons for taking a fresh look at the U.S. system of education. They provide a window of opportunity for action for a much needed reform of schools based on both research on how students learn and the professional expertise of teachers across the nation.

The second phase of Project 2061 has been an effort to unleash the talents of those who work directly with children day after day. Building on the strength of diversity, the San Francisco curriculum model draft offers a framework to prepare all of our children and young adults to become productive and participating members in a pluralistic and democratic society.

The San Francisco curriculum model does not claim to provide all the answers to our present educational challenge. It is an invitation to define new ways to organize people, time, space, knowledge, and technology so that both the school and the community address the needs of *all* students. The success of its implementation will depend on the will, courage, initiative, honesty, and collaborative spirit of all stakeholders in the educational process. Caught between eras, we face the unprecedented challenge to anticipate and prepare for a very uncertain future. However, the best way to predict and be ready for the future is to invent it.

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The National Project on Scope, Sequence and Coordination of Secondary School Science

Linda W. Crow
Bill G. Aldridge

The national science education reform called Scope, Sequence and Coordination (SS&C), is based on the analysis of thirty years of learning research studies, human resource data, and career access programs. This research base has led to the largest single financial effort in precollege science education since the post-Sputnik era of the late 1950s. The SS&C project initiated by the National Science Teachers Association (NSTA) has launched a major reform effort to restructure science teaching at the secondary level.

The Current Status of Science Education

Since the early 1980s, numerous reports have drawn attention to the failure of schools to educate students for a technological and scientific society. Surveys show that the majority of students leave secondary school without a basic understanding of science, mathematics, or technology. Most students stop taking science as soon as their school systems allow. Over half the students never take another science course after tenth grade. Only 19 percent of high school students take a course in physics, and only about 40 percent take chemistry. In addition, few college students major in a scientific field. The demand for scientists and engineers is not being met; nor are schools preparing citizens with the science background necessary for their future success.

A quick solution to this dilemma might be to remove the element of choice and require students to take existing science courses. This is no solution however: research indicates that the very structure of the U.S. educational system contributes significantly to students' lack of interest and achievement. Only the United States employs the "layer cake" sequence and structure of biology, chemistry, and physics at the high school level. All other industrialized nations of the world provide students the opportunity to study all the sciences over several years. They do not compress all of biology, chemistry, earth science or physics into one-year units. Nor do they stack the disciplines in the illogical layer cake order. American high schools established this ill-conceived structure in the late 1890s. When the middle school or junior high appeared, the high school's layer cake approach was copied and has remained in place ever since.

On top of this structure, our educational system also places filters, supposedly to identify the most gifted students and track them into course work that would prepare them for math and science, however, an examination of these filters reveals that they are not able to accurately identify the most gifted and often are barriers to students who are not seen as the traditional achievers in science. It is not surprising that these filters prevent large numbers of underrepresented groups from choosing careers in science, math, and engineering.

With demographic changes and the demand for a more scientifically literate population, such exclusions have been devastating. In the past, the United States has been a world leader because of its human resources. One need only read the news today to realize what effect its outdated education

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system has had upon economic and social changes.

The Research and Development Basis

Research over the last 30 years provides clear implications for science education reform. Piaget (1973) showed that concrete experiences should precede terminology and theoretical presentations. The appropriate sequencing of concepts was said to be essential by such notable researchers as Bruner (1960), Arons (1976), and Karplus (1976). All of this research supports the idea that concepts should be derived from experiences, with students acquiring a concept from experiences in different contexts. In addition, research on the "spacing" effect (Dempster, 1988) demonstrated conclusively that each science discipline should be taught over a period of several years, not concentrated into one year. Dempster's studies indicated that both achievement and retention are increased when spacing is used.

The research clearly shows how science should be taught to increase student understanding and achievement, as well as appreciation for the subject. It is no mystery. Instruction must begin with concrete experiences, build to the theoretical understanding and allow an adequate amount of time between experiences. An examination of our practices in the secondary schools suggests we do just the opposite. We begin by teaching for theoretical understanding as quickly as possible and cover as many facts as possible. Erroneously, recall is set up as the highest form of achievement and the collection of unrelated facts is the goal, at least in the minds of most students (Postman & Weingartner, 1969). It is no wonder that students soon become disenchanted with science and choose not to pursue it.

The last component of the SS&C Project is the coordination of the disciplines taught. Students often see biology, chemistry, earth/space sciences, and physics as separate entities having no bearing on one another. The SS&C program shows that the sciences are interdependent and fit together to provide explanations for phenomena.

The National SS&C Model

With these research conclusions in mind, Aldridge (1989) set out to devise a realistic model for the restructuring of science. The following table illustrates the original configuration of four science subjects taught over a six-year period. Notice that SS&C exposes students in the middle level grades to intensive descriptive and phenomenological experiences in the sciences. In later years, abstractions and theory will be the focus.

Table 1

Example of a Revised Science Curriculum for Grades 7 Through 12 in the United States.

	Grade Level						Total Time Spent
	7	8	9	10	11	12	
	Hours Per Week By Subject						
Biology	1	2	2	3	1	1	360
Chemistry	1	1	2	2	3	2	396
Earth Science	3	2	2	1	1	1	360
Physics	3	2	[illegible]	1	1	1	360
Total Hours /Week	8	7	8	7	6	5	
Emphasis	descriptive phenomeno-logical			empirical semi-quantitative		theoretical abstract	

Aldridge presented this initial model in 1989 and it met with tremendous support and interest. California and Houston, with funding from the Department of Education, became the first two SS&C Centers. In addition, a Coordinating Center was established at NSTA. The following year, additional funding was obtained through the National Science Foundation (NSF) to establish five centers–California, Houston, Iowa, North Carolina and Puerto Rico. All of these centers have embedded the essential changes described by Aldridge (1989) in their restructuring efforts. Each center has a somewhat different approach dictated in part by that center's particular characteristics. For example, the California Project began as a state-wide initiative, while the Houston Project is a smaller, more focused effort. The more recent centers–Iowa, North Carolina, and Puerto Rico–have their own regional perspectives. Iowa has attempted to take an "STS" approach, for instance. North Carolina has begun its work in the sixth grade, rather than the seventh. Puerto Rico is producing Spanish language materials and also is integrating mathematics into its restructured science program.

For the first time, an educational reform project will also be documented and evaluated on a national level. The Coordinating Center has asked Iris Weiss at Horizon Research, Inc, Chapel Hill, North Carolina to serve as national documenter. Records will be maintained as to what occurs in the project and each center, how the project succeeds or fails and how the SS&C changes are implemented at the different centers.

Support at the National Level

Through the efforts of the Coordinating Center, the SS&C project has provided *The Content Core* as a foundation for each center's selection of appropriate instructional materials and approaches. The focus is on the use and adaptation of existing instructional materials. The production of student materials will be left to professional publishing houses. Recently the California and Texas State departments of education have joined in a collaborative effort concerning textbook standards. As the two largest "textbook states", they have traditionally exerted a disproportionate (and not always positive) influence on most publishers. It is hoped that this cooperation can provide publishers with incentives to make the sweeping changes that are needed in student textbooks.

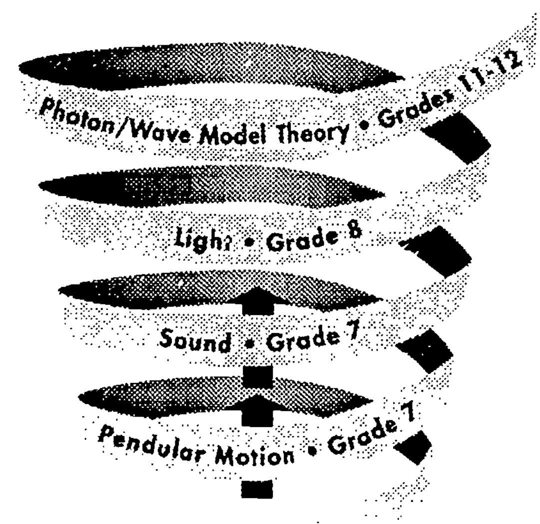
The Content Core is an evolving document that begins to answer the question of what in each scientific discipline is appropriately included at the various grade levels. This document was developed over a two-year period by content committees, following an analysis of existing materials. *The Content Core* is intended as a starting rather than ending point for instructional designers.

The Spiral Curriculum

In contrast to the current system, the SS&C program draws directly on the results of research. Concepts are sequenced and appropriately spaced out over time. They are included in the sixth through eighth-grade program only if they are handled in a phenomenological or descriptive manner. The spacing technique, which enables students to revisit concepts over a period of years, is carried out in the "Spiral Curriculum." The idea is not new, but has rarely been implemented in a school setting. For example, a study of harmonic (pendular) motion, could begin in the sixth through eighth grades, followed in later grades by a study of the phenomena of sound and light (see Figure 1). In grades 11 and 12, a study of wave theory which is more abstract, would be based upon the foundation of earlier experiences.

Figure 1

The Spiral Approach



Possibilities for using the spiraling approach abound in the other science disciplines, as well. In the middle grades, for example, students could begin a study of animal adaptations and behavior patterns. Later an investigation of fossils and geologic time could be added. The theory of evolution could ultimately be approached in a meaningful fashion. Again, the goal is not to have students memorize countless facts and definitions, a feat which has no relationship to true understanding. As Jules Poincare (1854-1912) pointed out,

> Science is built up with facts, as a house is with stone. But a collection of facts is no more a science than a heap of stones is a house.

The development of true conceptual understanding requires experiences first. Terms and definitions should be added later. This deeper understanding of science will allow students to answer fundamental questions on which SS&C is based: What do we mean? How do we know? What evidence do we have? Why do we believe? Later, students will be able to provide the evidence supporting important science models and theories. Remembering names and definitions should never be the ultimate focus in science. As stated in the California Framework:

> But a name should not become more important than the phenomenon being described, or than its empirical or logical relationships with other phenomena.

It is important not to believe that students can acquire a deep understanding of science by studying models or expositions of theories or models, no matter how well designed they are. Students learn through creating their own models and theories, not by reading descriptions. This means that students must be given opportunities to experience or observe a phenomenon, to revisit concepts over time and to develop answers to those four fundamental questions posed above.

Processes and Products of Science

SS&C points program designers toward sorting scientific knowledge in terms of the processes of science and the products of science. Both process and product are important. Each has many subcategories, some of which are more appropriate for certain grade levels.

The processes of science have long been defined but in many different ways. Since the names and numbers of processes vary considerably, a standard list and description was prepared as part of the national SS&C Project (Arons, 1989). Table 1 presents this list. Likewise, a description and ranking of products was developed (Aldridge, 1990), as shown in Table 2.

In the middle grade, SS&C classes, facts, terms, concepts, laws, models and theories are studied mainly in descriptive and qualitative, using words and visual models, but little mathematical symbols or equations. The processes of observing and inferring are emphasized, but gradually the students to use the higher order processes. At the ninth and tenth grades, the science program becomes more quantitative and symbolic, with greater emphasis on concepts and empirical laws.

Table 2

The Processes of Science

by Arnold Arons,
University of Washington.

Observing–Examining a system (or monitoring its change) closely and intently through direct sense perception and noticing aspects not usually apparent on casual scrutiny.

Inferring–Reasoning, deducing, or drawing conclusions from given facts or from evidence such as that provided by observation.

Measuring–Using instruments to determine quantitative or properties of objects, systems, or phenomena under observation. This includes the monitoring of temporal changes of size, shape, position, and many other properties or manifestations.

Communicating–Conveying information, insight, explanation, results of observation or inference or measurement to others. This might include the use of verbal, pictorial, graphic, or symbolic modes of presentation, invoked separately or in combination as might prove most effective.

Classifying–Systematic grouping of objects or systems into categories based on shared characteristics established by observation.

Predicting–Foretelling or forecasting outcomes to be expected when changes are imposed on (or are occurring in) a system. Such forecasts are not made as random guesses or vague prophecies but involve, in scientific context, logical inferences and deductions based (1) on natural laws or principles or models or theories known to govern the behavior of the system under consideration or (2) on extensions of empirical data applicable to the system. (Such reasoning is usually described as "hypothetico-deductive.")

Controlling Variables–Holding all variables constant except one whose influence is being investigated in order to establish whether or not there exists an unambiguous cause and effect relationship.

Interpreting Data–Translating or elucidating in intelligible and familiar language the significance or meaning of data and observations.

Developing Models–Creating, from evidence drawn from observation and measurement, a mental picture of a phenomenon (e.g. current in an electric circuit), the mental picture being then used to help rationalize the observed effects and to predict effects and changes other than those that entered into construction of the model.

Table 3

Products of Science

by Bill G. Aldridge,
National Science Teachers Association

Scientific Term–A word or words that scientists use to name an entity, object, event, time period, classification category, organism, or part of an organism. Terms are used for communication and would not normally include names given to concepts, laws, models or theories.

Scientific Fact–An observation, measurement, logical conclusion from other facts, or summary statement, which is concerned with some natural phenomenon, event, or property of a substance, which can, through an operationally defined process or procedure, be independently replicated, and through such replication has achieved consensus in the relevant scientific profession.

Scientific Concept–A regularly occurring natural phenomenon, property or characteristic of matter which is observable or detectable in many different contexts, and which is represented by a word, or words, and often by a mathematical symbol or symbols is called a scientific concept.

Scientific Principle–A generalization or summary in the form of a statement or mathematical expression which expresses a regular dependence of or measurements for a variable representing a concept on one or more other variables representing other concepts.

Empirical Law–An empirical law is a generalization of a relationship that has been established between two or more concepts through observation or measurement, but which relies on no theory or model for its expression or understanding.

Scientific Theory–An ordinary-language or mathematical statement createdor designed by scientists to account for one or more kinds of observations, measurements, principles or empirical laws, when this statement makes one or more additional predictions not implied directly by any one of such components. When such prediction or predictions are subsequently observed, detected or measured, the theory begins to gain acceptance among scientists.

Scientific Model–A representation, usually visual but sometimes mathematical or in words, used to aid in the description or understanding of a scientific phenomenon, theory, law, physical entity, organism, or part of an organism.

Universal Law–A law of science that has been established through universal acceptance and which has applicability throughout the universe. There are few such laws, and they are basic to all of the sciences (e.g. Law of Universal Gravitation; Coulomb's Law; Law of Conservation of Energy; Law of Conservation of Momentum).

Application of Science–Utilization of the results of observations, measurements, empirical laws, or predictions from theories to design or explain the workings of some human-made functional device or phenomenon produced by living beings and not otherwise occurring in the natural world.

Finally, in the eleventh and twelfth grades, there is a heavier use of equations, models and theories, with substantial mathematics coming into play. All grade levels require students to make applications, beginning at the personal level in the middle grades and advancing to global applications in the higher grades.

Project Assessment

Through a grant from the U. S. Department of Education, NSTA has begun the design of a performance-based assessment. Using a new CD-I format, the goal is to assess depth of understanding and to provide a diagnostic overview of students' science knowledge. The prototype consists of multi-tiers or levels and tries to find out how students know something is true, what evidence they have for a given belief, and how they would go about learning something new. The focus is upon the questions that form the basis of the SS&C Content Core. The tiers increase in complexity, allowing students to stop at any point. All students can succeed at the first level. As the item gets more difficult, more students are exited from the system.

The model is intended as an inexpensive and powerful method of administering performance-based assessments. In addition, this assessment through a branching of questions will test for cognitive knowledge. Many groups and individuals have discussed this approach, but none have produced anything similar. This prototype will be field tested in various SS&C centers.

Conclusions

Will the SS&C reform movement solve problems of classroom size, drugs and lack of parental interest? Obviously not. The SS&C initiative seeks to change the scope, sequence, and coordination and to demonstrate how these changes can be brought about in a variety of school settings. Many reform advocates focus upon the direction of the reform (bottom-up or top-down) while others focus upon a single participant of the school culture. Others demand that reforms solve myriad peripheral problems such as malnutrition and absenteeism.

But we must not lose the sight of the fundamental reason for this massive reform: to have students more interested in science and choosing science as a career; to expand the cross section of citizens interested in science and able to function in a society that is based on a scientific world view. The United States must develop its human resources more effectively. Our individual security and national well-being depend on it.

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The California Scope, Sequence and Coordination Project: A Case Study in Systemic Reform

Thomas P. Sachse

California's Scope, Sequence and Coordination Project is a statewide effort involving 199 schools. Coordinated by the state Department of Education, the science curriculum reforms in these schools are backed up by efforts to alter teacher credentialing requirements, preservice and inservice teacher preparation, university entrance requirements, assessment policies, and evaluation criteria for instructional materials. Cooperation among and efforts of the University of California and California State University systems, the Commission on Teacher Credentialing, the California Science Teachers Association, school districts, and others have made California's SS&C Project a genuinely systemic reform.

The California Scope, Sequence, and Coordination Project (SS&C) follows from an initial paper written by National Science Teachers Association (NSTA) Executive Director, Bill Aldridge, called *Essential Changes in Secondary Science: Scope, Sequence, and Coordination*, which was published in the January, 1989, edition of *NSTA Reports!* Aldridge wrote that two essential changes were needed to reform the secondary school science curriculum: first, reorganizing the curriculum to provide for a well-documented effect from psychological research, which suggests that learning is enhanced when spaced over time; and second, improving learning by taking into account the way students' cognitive capacities develop.

These two "essential changes" advanced by Aldridge suggested that the United States needs to take a very close look at the possibility of emulating a "concurrent" model of secondary school science curriculum that is used by Japan, the (former) Soviet Union, the People's Republic of China and most European nations. Rather than the "layer-cake" curriculum of the United States, which typically separates biology for grade 10, chemistry for grade 11, and physics for grade 12, Aldridge proposed that we move, as a nation, to the development of curriculum that concurrently teaches biology, chemistry, and physics, as well as earth/space science for one or more days a week over a four to six year period of time. In this way, the spacing effect would allow students to study physics, for example, for six years rather than a single year at the senior level (where only 21 percent nationally, and 13 percent in California, take physics before graduating).

The curriculum, thus spaced over six years, would need to take advantage of the possibility of using a developmental sequence that would start with the middle school program being largely phenomenological or descriptive, then moving on to basic measurement work and becoming semi-empirical (up to a level of basic algebra) for grades nine and 10, and then in grades 11 and 12, moving to more highly quantitative and largely theoretical understandings. In this way, the restructuring of secondary school science could accommodate both of the "essential changes" Aldridge (1989) recommended: the spacing effect as well as the developmental sequencing.

There are seven national centers for the Scope, Sequence, and Coordination (SS&C) reform. The first group, the National Science Teachers Associa-

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tion in Washington, D. C., provides the national coordination as described above. Another center is, of course, the California Department of Education in Sacramento with its 199 participating schools. Yet another center that began with the Department of Education funds at the same time as the California center is a collaborative effort between the Baylor College of Medicine and the Houston Independent School District where three schools are doing intensive work using this reform structure. Three additional centers established by the National Science Foundation include two universities in North Carolina, the University of North Carolina, Wilmington (David Andrews and Dick Ward) and East Carolina University (Charles Coble and Floyd Mattheis); University of Puerto Rico (Manuel Gomez) in San Juan, Puerto Rico; and University of Iowa (Bob Yager and John Penick) in Iowa City. The U.S. Department of Education recently added a seventh site by funding Anchorage Public Schools to begin SS&C planning under the direction of Emma Walton. These seven centers are currently the focal points for Scope, Sequence, and Coordination reform efforts nationally.

The California project started with funding from the U. S. Department of Education to 100 high schools and many of those high schools' middle grades feeder schools. With the addition of ten "alternate" schools, there are now 199 schools participating in the California restructuring effort: 100 high schools and 99 middle schools. These schools (or school pairs, when middle schools have joined the restructuring effort) received planning grants that averaged $8000 per school. The major endeavor involves the department chair (or other site leader) working with the science faculty at the high school and middle school to plan how to reformulate the secondary curriculum for those schools, in line with the "essential changes" recommended by NSTA.

The California Department of Education (CDE) is coordinating state level efforts to reformulate the science curriculum, credentialing procedures, university entrance requirements, and assessment policies, so that schools that restructure their secondary school science programs in line with these envisioned changes are not penalized but are, in fact, encouraged to make such changes. Ultimately, the most compelling coordination is done at the local level. Science teachers meet as a group for roughly 50 hours during a two-year planning process to develop their ideas for implementing a revised curriculum, including the use of new instructional materials, the possibilities for scheduling changes, and team teaching. The model curriculum developed by CDE is customized at the local level to meet the specific needs and interests of those teachers and their students.

Currently most of the reform work is done at the school level with occasional regional meetings and semi-annual statewide curriculum coordination conferences. These regional and statewide coordination meetings are for department chairs and other leaders involved in this project to share ideas and techniques. The real power of this effort is its networking–teachers to teachers, department chairs to department chairs, and feeder middle schools with their high schools.

In September, 1990, the National Science Foundation awarded a $1.5 million grant to the California Department of Education to provide the types of support that schools need as they make the transition from planning to implementation. There are five components to the NSF funded project:

- the establishment of ten "hubs" where a group of high schools (and participating middle schools) gather to share implementation techniques and participate in staff development;
- the brokering of university faculty to provide "demand-side" inservice that meets the staff development needs identified by the hubs;
- the creation of preservice reforms such that prospective secondary school science teachers learn to prepare for teaching in an SS&C school (the graduates of such credential programs would perform their practicum teaching at SS&C schools);
- the development of action research designs such that teachers could conduct classroom research on the efficacy and improvement potential for SS&C curricula; and,
- the continuation and expansion of documentation and evaluation.

In total, this NSF funding provides continued institutional support for SS&C schools and brings university faculty into the reform effort.

The NSF-funded effort is supported widely through science and science education faculties in the California State University (CSU) system. Inservice programs are coordinated by Crellin Pauling at San Francisco State University; preservice programs are coordinated by Herb and Bonnie Brunkhorst at the CSU San Bernardino campus; and action research opportunities are coordinated by Fred Goldberg at San Diego State University.

Documentation and evaluation of this work is combined through the efforts of Horizon Research, Inc. in Chapel Hill, North Carolina (which coordinates the national documentation of this endeavor), and by the Far West Regional Educational Laboratory in San Francisco, California. Horizon Research focuses on documentation, periodically collecting survey information from all of the participating schools sites and conducting case studies of the reform process in several California schools. Iris Weiss, President of Horizon Research, is working with Susan Arbuckle to coordinate the California documentation effort. The evaluation design is headed by Don Barfield and Steve Schneider from the Far West Lab.

Of course, the most precious human resource is the student population among participating SS&C schools. This project has made a very direct effort to recruit schools with high minority enrollments. Twenty of the original 100 schools have more than 75 percent minority students. Eighty-eight of the 100 have more than [illegible] percent minority students. The real effort is to create a challenging, non-tracked science program for all students. As historically underrepresented students succeed, we believe that more will stay longer in the science and technology pipeline. Specific inquiries are underway to the major university systems to ensure that students in SS&C courses are given credit for university entrance. Some schools have created honors, advanced placement or other specialty courses for the most advanced science students, but the basic design is a rigorous sequence for *all* students.

Leverage Points

The sheer scope and magnitude of the California Scope, Sequence and Coordination Project creates a point of leverage for the reform to build upon. With 199 secondary schools and many others interested in joining the reform, there are enough schools, teachers, parents, administrators and students to keep Scope, Sequence and Coordination in the forefront of the restructuring dialogue among California public schools. In addition, the strong combination of site leadership, university support, state department of education administration, and professional association support (provided by the California Science Teachers Association) enables the Scope, Sequence and Coordination effort to move forward on a variety of fronts at the same time. But the most important aspect of this reform is the number of schools and teachers involved. This mass of support creates enough momentum to move roadblocks which would typically work to erode support for pilot programs such as SS&C.

One particularly troublesome barrier to the reform of secondary school programs in California (and many other states) is the university expectation for the traditional layer-cake curriculum consisting of laboratory-based, college-preparatory biology, chemistry and physics courses. In California, the University of California Office of the President (UCOP) establishes guidelines for high schools' petitions for approval of "university appropriate coursework." The three segments of the higher education system in California, including the Community Colleges, the California State University and the University of California, have jointly adopted six "A-F" requirements which include the D requirement for laboratory science. High schools must describe any formal additions to the college-prep science sequence and have the curriculum approved by the Board of Admissions and Relations with Schools (BOARS). Early on, several schools in the Scope, Sequence and Coordination Project petitioned the University of California system to approve the new courses, only to find them rejected with little commentary or assistance. With strong urging from the California Science Teachers Association, faculty from the various university segments met with project leadership and a number of petitioning schools to jointly discuss the potential for allowing coordinated science to meet the laboratory science requirement. After several discussions and significant improvement in the caliber of submitted curricula, new SS&C programs are now being approved. With the University of California now supporting the SS&C reform, and a better understanding among the science teachers and the university BOARS faculty, it is possible for each group to coordinate better the processes by which university entrance decisions are made. This creates an opportunity for many other schools who had been waiting to see whether UCOP approval would be granted to now join the SS&C reform in California.

Another major facet of science education in California is the California Assessment Program (CAP) in science. For many years, the science CAP involved only the eighth grade and used only multiple choice items. In 1990, CAP moved more toward "authentic assessment" of science programs, using performance tasks and open-ended items to gauge the achievement of students in more rigorous science programs. As a consequence, it became possible to assess students' abilities in the traditional science programs in a way that would mirror the traditional coursework. With the advent of SS&C, the CAP office was able to create an "authentic" representation of coordinated science. Kathleen Comfort, Science Consultant for the California Assessment Program, working with the Science Assessment Advisory Committee generated a "criminal investigation" cal. d the "Obechki Mystery," in which students needed to use techniques from the earth, life and physical sciences to unravel a forensic mystery. With CAP now creating authentic assessments of coordinated science, once again science teachers and science specialists (not to mention administrators, parents, school board members, and others) are able to see that the state is united in looking towards an assessment program that supports Scope, Sequence and Coordination rather than simply reifying the status quo.

Similarly, the Commission on Teacher Credentialing (CTC) has worked with the California Department of Education to issue a joint memorandum which describes credentialing procedures that authorize the teaching of coordinated science. Coordinated science is sometimes taught by a single individual, but is just as often taught by two or more teachers in a team teaching pattern. Whether a single teacher or several teachers teach coordinated science, the Commission on Teacher Credentialing has created an opportunity for districts to reexamine the credentialing issue relative to SS&C in a more positive framework. They suggest eight possible credentialing avenues for teaching coordinated science. Once again, the number of schools, teachers and administrators interested in this reform, coupled with the state-level responsibility for the project have galvanized a swifter and more appropriate reaction from the system which favors coordinated science.

Another potential roadblock to the SS&C program has been the lethargic response of commercial publishers to creating coordinated science materials. Because of California's leadership in the development of evaluation criteria for instructional materials that favor coordinated science and because of the large number of schools that adopt instructional materials in California, three publishers have submitted coordinated science materials for the 1992 California adoption process. Programs submitted by Holt, Prentice-Hall, and Glencoe-Merrill were submitted on April 10, 1992, for the instructional materials evaluation process. If one or more of these instructional materials survives the gauntlet of state adoption, there could be a potential market of well over 100 middle schools to use these 6-8 or 7-9 programs. Other materials are in the process of development in the United States. Canada, England, Israel, and Australia may also offer coordinated instructional materials to meet this need for high quality, rigorous, instructional materials.

The preservice reform led by Herbert and Bonnie Brunkhorst at CSU San Bernardino has done much to move the SS&C project along. Not only are preservice programs being redeployed in an effort to prepare prospective teacher candidates with a background in coordinated science, science educators at CSU campuses are now recreating science methods as well as undergraduate science programs to reflect a coordinated approach to the teaching and learning of science. Rather than always having to create new inservice programs for the generations of new teachers who are inadequately trained for the new reforms, this preservice mechanism will allow teachers of the future to be prepared in a way that enables them to teach the restructured, coordinated science.

The California Science Teachers Association (CSTA) has been of major assistance to SS&C. Zack

Taylor, Executive Director of the California Science Teachers Association was originally project manager for SS&C at the California Department of Education. His stature among teacher leaders statewide and his acumen in mobilizing the professionalism of science teachers has created a much stronger CSTA organization than existed just a few years ago. As part of the long-term dissemination efforts for SS&C, the California Department of Education now regularly publishes an insert to the CSTA newspaper, *California Classroom Science*. The insert is called "Restructuring Science" and is four tabloid size pages, published five times per academic year. Each issue offers a variety of informational items and details national news from the NSTA Coordinating Center or one of the other five national test sites. "Restructuring Science" is mailed to 22,000 science teachers and several hundred other science educators around the nation. This provides a forum for examining how coordinated science is developing in California and gives people insight into the kinds of issues and problems that must be overcome in mounting this large-scale reform agenda.

The specialized treatment of historically underrepresented groups in California schools is on the minds of every SS&C teacher. The SS&C program in California started off in many schools with larger numbers of minority group students because of this interest and our expectations for the success of historically underrepresented groups in coordinated science. Certainly too many had not succeeded in the abstract, quantitatively rigorous layer-cake programs of the past. A separate task force has been established for historically underrepresented groups in SS&C. Maria Lopez-Freeman, from the California Science Project, and Helen Kota, Hub Coordinator in Conejo Valley Unified School District, have assembled a small group of 12 minority SS&C science teachers in the hopes of creating a specialized agenda for future hub meetings. Thus, every hub and every SS&C site in California has the opportunity to address the special needs of underrepresented groups.

Other staff development mechanisms will be necessary to provide content updating and issues relative to coordination. In particular, there are substantive content issues about what science can be coordinated and where mistaken connections are to be avoided. In addition, certain kinds of pedagogical issues affect the SS&C program in California, some of which include sheltered science techniques for helping limited English proficient students succeed in SS&C; team teaching techniques; innovative scheduling options; and procedures and policies for working with parents, counselors, administrators and others who need to know more about a SS&C project in order for it to be successful. These and many other staff development initiatives around the use of new instructional materials created expressly for the SS&C project will require funding and the time commitment of SS&C teachers to learn more about teaching coordinated science.

Issues for the Future

Several especially challenging issues will need to be confronted in the not-too-distant future. Some districts are already considering moving to coordinated science in all their schools. While potentially a boon to the project and an indication of its reception in these districts, that replication may be moving more quickly than is desirable. Many policy and practical questions remain unresolved at this point and it may be premature for these districts to move so swiftly to district-wide coordinated science adoption. In addition, there is the question of resources; too many teachers and schools adopting coordinated science can threaten the viability of the entire enterprise when already thin resources are spread to a much larger group of participants.

It is likely that there will be some losses and changes over the course of the next several years. Some schools have already departed from the SS&C reform because: (a) the leadership left, (b) the school closed, (c) the administration changed its collective mind, or (d) some teacher groups failed to be able convince themselves and their student bodies of its potential. An understanding of program implementation success and failure will be necessary in the future as new schools are invited or encouraged to participate in the SS&C reform in California.

Perhaps the most challenging question in the near future is the movement towards convergence rather than creativity. The "100 Schools Project" began with a sense of openness and innovation, such that the two essential changes advocated by

Bill Aldridge could take a variety of forms and a variety of implementation styles. It was intentionally a divergent project where a school could create its own sense of what coordinated science would be fcr its students. Just three years into the project now, many schools are asking for a more convergent tone to emerge. They feel the original need for innovation and freedom has diminished to the point where they are ready to agree to common assessment measures with an understanding that their programs would be judged and might be modified accordingly. While it is still very early in the reform process, there may be important reasons to move towards an appropriate level of convergence. Among these reasons are the assessment vehicles, including the California Assessment Program and related accountability programs such as the Program Quality Review (PQR), the Western Association of Schools and Colleges (WASC) accreditation reviews, and the aforementioned UC Office of the President curriculum approval process. These review mechanisms would tend to push toward a more clear-cut, recognizable form of coordinated science for schools in California.

The California SS&C project has many elements. It is very much a grass-roots efforts led by the teachers; it is formally directed by the California Department of Education with regional coordinators in northern, central and southern California; it is supported by university faculty, especially those on California State University campuses; and it is warmly supported by administrators and parents in a good many sites. In addition, the California Scope, Sequence and Coordination Project has had very strong support and receptivity by the UC Office of the President, the California Science Teachers Association, the Commission on Teacher Credentialing, and the California Assessment Program. A major issue the entire project has yet to grapple with will be the degree to which students and schools are given the freedom to create SS&C as they see fit or whether they should be asked to move towards some common understanding of the "California version" of SS&C. While there are many parts of this complex puzzle in place, there is still much to be done.

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A Case Study: Success and Disappointment in One Educational Plan to Support Scope, Sequence and Coordination in California

Robin McGlohn

Philip and Sala Burton Academic High School in San Francisco was one of 100 California high schools initially chosen to plan and implement a site-designed curriculum based on the Scope, Sequence, and Coordination concept of the National Science Teachers Association. A feeder middle school was included in the project. A general 6-12 and a specific 6/9 integrated curriculim was planned and implemented in 1990. At present the schools have curricula in place and are awaiting additional funding to complete the project. This article describes the concept of the integrated curriculum and the process which took place in planning and implementing this aspect of the SS&C.

As but one example of California's SS&C Project, San Francisco's Phillip and Sala Burton Academic High School may serve to demonstrate the state's innovative and far-reaching attempt to improve science education. In conjunction with one of its feeder middle schools, Burton implemented an Integrated Science Curriculum (ISC) for the 6th through 12th grades based on the SS&C in September, 1990. Now a year and a half later, the program is still intact in the 6th through 9th grades but has been suspended for the 10th, 11th, and 12th grades, due to lack of funding.

Until the fall of 1989, the science department at Phillip and Sala Burton Academic High School in San Francisco had been teaching from the traditional science curriculum sometimes called "layer-cake." All 10th grade students took biology and all 11th graders took chemistry. Twelfth grade students took either physics, physics AP, or physiology depending on previous performance in science and math. There was no 9th grade science offering, and thus, a year's hiatus in science instruction occurred between the eighth and tenth grades. The curriculum had existed since the establishment of this academic alternative high school in the San Francisco Unified School District (SFUSD) in 1984.

As the curriculum sequence continued unchanged in the ensuing years, the science teachers became increasingly displeased with the lack of success of the 11th and 12th grade students. Nearly 50 percent of their students failed chemistry in the 11th grade and had to retake it as seniors with the commensurate decreased enrollment of seniors in physics. A disproportionate number of women as well as black and Hispanic male students never took physics. Attempts to find ways to increase motivation and achievement in the science courses had improved little. As can readily be imagined, teacher frustration had become a serious problem in the science department and was the subject of many department discussions. It must be noted, too, that the Burton science faculty are not stereotypical inner-city victims of burn out. In hopes of learning new ways to improve their teaching methods, the science teachers actively worked at their professional development by attending district workshops, the Exploratorium Teacher's Institute, Lawrence Hall of Science, and discipline-specific meetings such as the AAPT and the ACS. A completely new curriculum approach had not been considered, although they felt a critical step in improving the curriculum was to be a 9th grade sci-

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ence course. Science teachers were unanimous in their opinion that a properly designed 9th grade science course should provide more receptive and capable students for the remaining science courses. Many barriers to that seemed insurmountable, however, including such problems as what ninth grade course could be dropped from the current curriculum, how the teachers could get the time to plan this course adequately, and where additional resources would come from.

Fortuitously, in November, 1989, every high school in California received a solicitation from the State Department of Education to submit a grant proposal for a Scope, Sequence, and Coordination (SS&C) oriented curriculum for high schools. Approximately $10,000 would be made available to "100 Schools" to commence planning and implementing some form of curriculum adapted to the SS&C. The science faculty at Burton saw the opportunity as no less than an answered prayer. As we reviewed the instructions of the grant proposal, we were even more excited as we realized that we could expand the curriculum to include one or more middle schools. Our planning could encompass grades 6 to 12, rather than just the high school grades.

A preliminary discussion between our science department chair and the chair at one of our feeder middle schools, Dr. Martin Luther King Jr. Academic Middle School, showed that the middle school science staff was extremely interested also. We met initially as a group in December, 1989, to ensure that we understood the grant and, if we agreed to apply, to decide what type of curriculum we wanted to implement. Most of us met the science teachers from the other school for the first time. Teachers of the two site groups were incredibly enthusiastic as they became aware that SS&C offered them an opportunity to design a curriculum based on what they knew about the subject material and their students. For the first time in their teaching careers, they would be entirely responsible for their curriculum and together they could design a curriculum to solve problems common to the subject material and the community they serve.

As a result of that very positive initial meeting, it was decided that Burton would submit a grant proposal incorporating the two schools. The faculties were forced to determine the type of curriculum they wanted to propose. Although three basic choices were suggested by the state, schools could propose any other models they might want to try:

a. **Invert** the traditional high school curriculum by starting with physics, then teach chemistry, and end with biology, leaving the middle school curriculum mostly as is. Earth science would be included as feasible.

b. **Coordinate** the high school and middle school curricula so that a certain amount of each of the sub-disciplines would be covered separately each semester or year, spiraling upward each year as envisioned by the Science Framework.

c. **Integrate** all the sub-disciplines by teaching to a topic in which all or most of the sub-disciplines would be included as the need for using that sub-discipline arose. Here again, the rigor of the material would spiral upward as per the Science Framework.

After another meeting, we decided to apply for the grant based on the integrated curriculum. This was our rationale:

- Burton was not achieving its goals with the current layer cake curriculum.
- King was already teaching science in a coordinated curriculum.
- Burton's students approached the traditional "boxy" curriculum as material to be suffered for the year and then forgotten. *"I've got to take chemistry (biology, physics), but if I can just get through it, I won't have to think about it any more after the last final."*
- Teachers were hard-pressed to relate subject material to students' lives.

The principals of both sites shared faculty excitement about the opportunity to change the effectiveness of the science curriculum. Burton's principal agreed to make space for the 9th grade science course and committed the "earnest money" required by the grant. The District agreed to be fully supportive of the school's effort within the limits of its resources.

Submitted in January, the proposal was accepted in February, 1990, with $8,400 granted by the state for planning time and incidental expenses.

We were on our way!

It must be acknowledged that these science teachers, from only two San Francisco schools, were not attempting to design a model to be used by all high school/middle school teams. Burton and King science faculties were excited about the opportunity to design a curriculum for *their* students. Certainly not every school matches the demographics and curriculum structure of our two schools:

Philip and Sala Burton Academic High School

1,200 Students
35% Asian
25% African-American
15% Hispanic
20% Other minorities
5% Caucasian

Consent Decree

- Settlement of suit by NAACP against City/ County of San Francisco and State of California.
- Created in 1984 as an academic high school.
- Parents send in application/chosen by lottery/no entrance requirements except graduated from the 8th grade.
- Closed campus
- Dress, conduct and attendance codes
- Seven academic classes per day.
- Goal is to meet admission requirements of University of California system.
- 175 out of 195 graduates in 1991 entered two or four year colleges.

Curriculum

- Four years math
- Four years English
- Four years science (three years before implementation of SS&C)
- Four years of social science
- Three years of computer science
- Three years of foreign language
- Two years of physical education

Electives

- Fine Arts
- Choir
- Band/orchestra
- Drama
- Varsity/junior varsity athletics

Dr. Martin Luther King Jr. Academic Middle School

560 Students
15% Asian
40% African-American
24% Other minorities
13% Hispanic
8% White

Consent Decree

- Settlement of suit by NAACP against city/ county of San Francisco and State of California.
- Created in 1984 as an academic middle school.
- Parents send in application/chosen by lottery/no entrance requirements except graduated from fifth grade.
- Goal is to prepare students for the academic high schools
- Closed campus
- Dress, conduct and attendance codes.
- Six academic classes per day.

Curriculum

- Three years math
- Three years language arts
- Three years science
- Three years social science
- Three years physical education
- Three years electives sixth grade; 1/2 year computer skills; 1/2 year Latin.

The group which met in the Spring and Summer of 1990 to plan the SS&C curriculum consisted of four teachers from King and six from Burton. We had some marvelous resources available to help us get started:

- Draft, California Science Framework
- *Science for all Americans (Project 2061)*
- Broad range of teacher backgrounds
- Burton Science Chair member of Project 2061.
- King teachers experienced in grants and staff development
- Commitment of administration and district
- Cooperative attitude of staff
- SS&C computer network (California State

Universities) being implemented

- University advisor (Dr. Kathleen O'Sullivan, SFSU) member Project 2061.

We met at school and in our homes for a total of forty hours as supported by the grant funds, and there were also many on-site discussions during the school days. We felt that we were working as one team to realize the goals we had articulated:

- Make science available to all students
- Foster an interest in science
- Prepare students for post-secondary careers
- Build self-esteem in each student
- Help students to appreciate the method of scientific study
- Build a student's confidence in own ability to learn
- Get students in the habit of taking responsibility for learning
- Help students to learn how science/technology relates to all aspects of their lives
- Help students to become scientifically literate in order to be able to make responsible and ethical decisions
- Increase parents' and community involvement in education

The curriculum team decided to implement the curriculum at the start of the fall semester in order to build upon the momentum of the enthusiastic planners. They felt delaying for a year or more to ensure a "perfect" curriculum would be wasteful and that the sooner they gained experience, the sooner they could evaluate and modify to improve its original work. Furthermore, this initial experience would help in the design of the 10th and 11th grades. King was making topical, not fundamental, curriculum changes, and there hadn't been a 9th grade science curriculum at Burton.

Confident that the students were not being jeopardized by rapid implementation the teams decided to use a topic-based curriculum in the middle school and repeat it in the high school. This would permit a spiral, using the students' recall to improve their learning and make connections in an easier manner:

- 6th/9th Self - The human body as interacting systems
- 7th/10th The Local Environment
- 8th/11th The Global/Universal Environment
- 12th Specific content courses

The chronology for the first year (6/9th grade) of implementation follows:

- 3 weeks Process skills
- 5 weeks Digestive system and nutrition
- 6 weeks Circulatory & respiratory systems (hereditary: asthma, sickle cell; health issues such as lung disease).
- 2 weeks Excretory system, carbon cycle, integumentary system (hygiene)
- 6 weeks Skeletal and muscular systems (exercise, physical anthropology, simple machines, levers, pulley)
- 7 weeksNervous system (light, sound, drug education, psychology, perceptions).
- 8 weeks Reproductive system, genetics, health issues.

An unmentioned benefit of SS&C planning is the integration of programs, departments, and even different school sites. About this time the two faculties recognized how completely they were functioning as one department rather than representing their individual sites. Thus, in that spirit they adopted the title of the "Kington" Science Department to represent their unity of purpose.

From that point on the two faculties started working on both school's curricula, meeting to share and critique their achievements. Totally involved in planning and fully expecting to repeat the planning sequence the following two years, they understood from the beginning that this would be an ongoing project and that they would be receiving funding to complete their implementation of the 7th/10th and 8th/11th curricula.

The curriculum team recognized potential problems that would require resolution. First, there was the problem of approval of the complete integrated curriculum by the University of California system. The team chose to use the titles of already accepted courses in the interim since it could not submit a 9-12 curriculum until confident that what it submitted was ultimately desirable. They had to be able to show that the integrated curriculum, in fact, provided the learning supposedly accomplished in three years of the traditional curriculum. Second, there was the matter of credentials. If the faculty planned to utilize all the sub-disciplines and increase the rigor of the course with each subsequent year, it would either team teach or use

"Renaissance" teachers who were credentialed to teach all the sub-disciplines. The team determined to use the Renaissance teachers for the 9th grade but intended to move into team teaching for the 10th and 11th grades.

The implementation of the 6/9 curriculum in September, 1990, went quite smoothly. The teachers were pleased with their progress in spite of significant resource limitations (e.g., there was no text, since no text had been written specifically to support an integrated curriculum; Burton relied on the biology texts on hand as class sets and made handouts for the physical science aspects of the course). As the course developed in the fall, excitement built in contemplating what the 7/10 curriculum would look like. No additional funding was made available for the next year's planning, however, and the team began to feel uncomfortable as it remembered the amount of work that had been put into the first year's planning.

By the beginning of the spring, 1991 semester, the realization hit home that funding would not be forthcoming from the State for planning needed to continue the high school portion of the integrated curriculum . We cast about for any areas of grant money which existed and which in any way fit our situation. We applied for the 1990-1991 Tapestry Grant but were not selected. A State grant with adequate money for planning was not available because it involved restructuring of the entire school, a task which transcended the immediate goals of our integrated science curriculum.

Unwilling to give up, the Burton teachers modified the 10th grade curriculum. Instead of continuing with the integrated curriculum, they attempted to adhere to the topical chronology in order to remain in step with King. The 10th grade was restructured to include one semester of earth science which would focus on the local region. The second semester would consist of life science which, coupled with the life science gained in the 9th grade, would complete the life science requirement for the 10th graders. King remained faithful to the original planning, building a 7th grade science curriculum based on the Bay Area.

It became very apparent near the end of the first semester of the second year of our implementation that the 10th grade curriculum was in serious difficulty. Although the 10th grade teachers had originally agreed to the restructured version of an integrated curriculum for sophomores, they lacked the feeling of accomplishment such as that with the 9th grade. Tenth grade teachers were succeeding in various degrees with the "life-ring" of an earth science curriculum for the first semester, but the life-science teachers had serious concerns about the remainder of the year. What would satisfy the learning that they felt the students needed to accomplish in the next three semesters with the prospect of an 11th grade which didn't seem to offer an opportunity to include much life science? Also, did the 10th grade curriculum truly provide the students a base that would allow a spiraling of chemistry into the 11th grade? Could students learn enough for the school to claim that they had satisfied a "year of chemistry"? The consequences of lack of adequate planning for the 10th grade were becoming quite evident and the morale of the 10th grade teachers slipped badly.

The Burton teachers decided just before the end of the first semester of the 1991-92 school year that they could not continue with our initially exciting changeover to a six year integrated science curriculum. Given that the 10th grade was already in trouble, an 11th grade curriculum implemented without firm planning would be a disaster for the current 10th grade students. It was agreed, therefore, that Burton science teachers would "keep the faith" by retaining what they believe to be a highly successful 9th grade integrated curriculum, then revert to the traditional layer-cake for the 10th, 11th, and 12th grades. If funding for two full years of curriculum planning can be found (approximately $20,000), this year's 10th grade curriculum will be reviewed by the 10th grade teachers to develop a 10th grade integrated curriculum for implementation in the 1992-1993 school year. The funding must be adequate to allow follow-up planning for the 11th grade as was originally conceived.

It would be a great understatement to say that the "Kington" teachers have been deeply disappointed by their inability to carry out the original plans for the implementation of the SS&C. The failure to continue is solely due to the lack of funding to provide proper planning time. The faculties believe strongly in the way their initial implementation of the integrated curriculum in the 6th and 9th grades has brought all the science sub-disciplines to every student. Those who have taught the 10th grade have seen how the 9th grade integrated curriculum prepared the students to move upward in their knowledge of the world around them. The SS&C has been accepted by King's science teachers, and they are pleased with their progress. They have been able to use other funds from the School Improvement Program (SIP) and the San Francisco Education Fund to initiate planning for the 7th and 8th grade integrated curriculum. There is, however, real apprehension as to what effect Burton's indefinite delay of the original long-range plan will have on King's teachers. The deleterious effect of the lack of planning time for all members of the "Kington" Science Department during the first year of implementation has become increasingly obvious. The faculties have grown apart and have lost, hopefully only temporarily, the collegiality which was felt so strongly during the initial planning.

As to such things as course accreditation, credential acceptance for team teaching, long-term assessment, and adequate resource materials, these problems that the integrated curriculum raises for the high school will be addressed when the additional time for planning is once more available to the high school faculty. We science teachers have great hope for a full curriculum, but with the present halt in further planning of the SS&C at Burton, we are unable to build on our initial and very successful accomplishments.

Toward Professional Practice: The Role of National Science Teacher Education Standards

Steven W. Gilbert

Currently, nearly 700 of approximately 1200 colleges and universities purporting to have a state-accredited teacher education program are not accredited by the National Council for the accreditation of Teacher Education (NCATE). Only two states require that institutions acquire its accreditation. This article addresses the need for national standards in teacher education with emphasis on science teacher education.

It seems generally agreed that the educational system in the United States is not performing at an acceptable level, particularly in mathematics and science. The sources of its problems are undoubtedly complex and diverse, but the lack of a strong set of national standards for entry into the profession should be held to be at least partly to blame.

Education is distinctive among the major professions in that its standards for entry and practice are primarily developed and enforced by state agencies and legislatures, rather than by the profession itself. While institutions may gain nongovernmental professional accreditation by meeting the standards of the National Council for the Accreditation of Teacher Education (NCATE), such recognition is generally not required.

The result is a fragmented system of standards and regulations which are not always based upon the needs of the students or the best knowledge and practice of the profession. Today, in this country, there are fifty different sets of legal standards for state program accreditation and teacher licensing. Moreover, these standards, some of which are weak to begin with, have proven vulnerable to administrative and political pressures to further ease the passage of certain potential teachers into the profession. The same system holds teacher educators accountable for bureaucratic or legislative initiatives over which they have little or no control.

Unfortunately, the purpose of professional accreditation and certification appears at times to be poorly understood and indifferently supported by teacher educators. This situation must change, for professionalization of our contemporary standards of practice may well be the key to remedying some of the serious weaknesses which currently plague the nation's educational system.

Professionalization of Teacher Education

Does a true teaching profession exist, or is teaching a quasi-professional activity which has yet to come into its own? In an extensive study of teacher preparation practices in the United States, Goodlad (1991) found teacher education programs to be marked by low prestige, lack of coherence, separation of theory and practice, and a regulated conformity in which programs are driven more by ongoing practice and bureaucratic concerns than by a coherent knowledge base. These findings do not support the idea that education is a true profession.

In the United States, most of the major professions, including law, medicine and architecture, have entry-level professional standards for certification of individual practitioners and accreditation of programs to prepare them (Wise, 1991b). Novices are required to participate in an extensive pe-

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riod of specialized training and a substantial supervised internship, during which the norms, skills and knowledge of the profession are transmitted. In these professions, standards of entry are determined by professional practitioners rather than by those outside of the profession. State boards made up of members of the profession are active in licensing, i.e., governmental approval to practice, and these boards reinforce a national system of accreditation by requiring that students graduate from institutions accredited by the professional associations (Darling-Hammond, Gendler, & Wise, 1990; Wise, 1991a).

Almost 700 of the approximately 1200 colleges and universities purporting to have a state-accredited teacher education program are not accredited by NCATE, and, although a number of states have agreed to cooperative relations with the Council, only two states require that institutions acquire its accreditation. State agencies and legislatures have been reluctant to surrender or share their control over educational practices, despite their concerns about poor educational performance, and despite the fact that most state accreditation standards are weak in comparison to the professional standards adopted by NCATE. In some states, for example, approved science education programs require no more than 12 credits of content preparation in a teaching field.

Teacher preparation has been perceived as being so weak that some teachers, administrators and legislators have questioned the need for it. This has resulted in a paradoxical situation in which the weaknesses of past practices have led to actions which are likely to further weaken the practice of teaching, including the removal of licensing restrictions, the development of alternative certification programs, which are now available in 30 states, and mandatory restrictions on the number of hours which may be required in professional education.

In stating the case for district-run alternative certification in Alaska, Jarvis (1991) argued that "...school boards, school districts, school administrators and teachers can better educate the new teacher without interference from traditional university bureaucracies which, in many cases, are not in step with the 'real world'"(p. B6). While Jarvis' statement reflects the doubts of some educators and legislators about the efficacy of university teacher education, Darling-Hammond (1991) has found that the weight of available research supports the need for full preparation of teachers. Her review of 65 studies found "...consistently positive relationships between student achievement in science and the teacher's background in both education courses and science courses" (p. 6). Although some alternative certification programs are educationally sound when undertaken in collaboration with university faculty or teacher education programs, others are essentially apprenticeships that require less rigorous and demanding studies and experiences than the traditional programs they replace (Wise & Darling-Hammond, 1991). Furthermore, their effectiveness in some cases has been lessened by failure to ensure that program requirements are fully met. Smith (1991) found that attendance at meetings and proper supervision of experiences in New Jersey's alternative programs were frequently lacking.

Well-run alternative certification programs undertaken with appropriate expertise, commitment, and regard for professional standards can make a positive contribution to teaching. It is questionable, however, whether most school districts alone, especially small districts, have the necessary time, resources or expertise to develop and sustain such programs. The ideal program would combine the best practices of school districts and colleges or universities, as the movement toward Professional Development Schools is intended to demonstrate. The potential contribution of higher education stems from its synthesis of knowledge and research, its focus on the process of teacher development for teaching in a variety of situations, and its capacity to move the profession beyond the accepted limits of day-to-day practice.

No other profession devalues formal learning like education itself, perhaps because teacher educators are only beginning to develop a substantial and coherent research base to guide their practices. As this knowledge base evolves, it will become even more important for all educators to support the development and implementation of professional standards which require substantial and significant preparation for teachers before they enter the classroom. Only in this way can theory and practice converge to form the basis for a true profession.

Accreditation Standards for Science Education

Since 1986, standards written by the National Science Teachers Association (NSTA) have been adopted by NCATE as the standards for science teacher education programs. As a constituent member of NCATE, NSTA has participated in the evaluation of hundreds of science teacher education programs. Its standards are for programs designed to prepare elementary science specialists, middle school science specialists and secondary science teachers. The standards for a secondary program are broken down into a core set of requirements which apply across disciplines, and specific requirements for each of several disciplinary areas: biology, chemistry, earth science, general science, physical science and physics (National Science Teachers Association, 1991).

Through its participation in NCATE, NSTA has been able to impact programs across the country. In the process, its standards have been widely discussed, receiving strong support from some science educators, and criticism from others who sometimes regard the standards as unnecessarily burdensome or restrictive infringements upon academic freedom. Legitimate concerns have surfaced which will need to be dealt with if the standards are to be widely and completely adopted by states and institutions. Concerns have particularly been expressed about the effect of the standards on small rural colleges and universities and on the supply of science teachers to small rural school districts.

In the former case, Finson (1990) and Finson and Beaver (1990) have expressed concern that small rural institutions are unable to meet the teacher education standards because of the additional requirements for personnel, facilities and courses which the standards impose. They contend that the loss of such institutions would be detrimental to rural education in general. However, the extent to which such institutions actually affect the supply of rural teachers has not been demonstrated. In the midwest, at least, it appears that the majority of science teachers come from large programs. Furthermore, small institutions are by no means all rural.

Gilbert (1990), in a review of three cycles of NSTA/NCATE reviews including 75 institutions, found only a small relationship between the size of a program and compliance with the standards. Since the standards have only been included in NCATE reviews since 1986 and even now are not widely understood, it is not surprising that surveys such as Finson's, and a report by Barrow (1987) show that many programs do not fully comply with them. Although small size can certainly add to the difficulties of achieving full compliance, the fact that small programs do meet the standards is argument against the existence of an intractable size barrier. If, in fact, such a barrier is encountered, then it is legitimate to question whether the institution should be preparing science teachers.

A second, related criticism is that the standards are designed to educate specialists in the various disciplines, e.g., biology, while rural schools need generalists licensed in several different science subjects. At the present time, the standards are indeed intended for that purpose. NSTA standards require that a secondary science teacher earn at least 32 semester credits in his or her teaching field.

But to meet the demand for rural science teachers, a number of states including Ohio, Texas, Michigan, New Mexico, and Nebraska accredit broadfield programs which allow a teacher to earn a license to teach in three or more science fields with as few as 12 semester credits in each field. Such programs are clearly at odds with the standards, and institutions offering such programs are not in compliance with the NSTA/NCATE standards.

Teaching minors, which may require as few as 16 semester credits, and which seldom include specific methods instruction, are often required along with a major program which meets the standards. Minors, like broadfield programs, are intended to ensure that novices will be able to teach in more than one field. Although minors do not meet the science standards, NCATE policy is to ignore such minors, for purposes of review, except when there is no major preparation offered in the field. While this policy is expedient, it seems to defeat the purpose of accreditation by linking weak to strong preparation.

In Texas, Option II programs which require a minimum of 24 semester hours in each of two teaching fields offer a compromise between major/minor and broadfield preparation. While this kind of program is weaker in any one area than a full major, it has the advantage of lessening the impact of a weak minor, and it is stronger in all ways than a broadfield program. Option II-type programs are found in a number of states and, although they are in conflict with the current NSTA standards, should be investigated more closely.

Teaching minors, Option II's and broadfield programs offer much less content preparation than major programs but since they may be required by state regulations, they are often difficult for institutions to modify or eliminate, even should they choose to do so. Institutions not required by regulations to offer broadfield programs may still choose to do so in order to educate students with backgrounds which are competitive in the rural job market.

Recent moves toward the development of more interdisciplinary curricula have increased pressure on the NSTA to be more flexible in terms of course and credit distributions. In fact, it can be argued that a large part of the problem of staffing rural schools is created by the relatively rigid boundaries between the traditional disciplines which require subject-area specialists. Such divisions have come under increasing attack. *Science for All Americans* (American Association for the Advancement of Science, 1989), for example, recommends weakening or eliminating boundaries between the traditional disciplines in precollege science. A curriculum implementing such a proposal would require teachers familiar with integrating concepts and methods of investigation rather than a single field of study. Similarly, NSTA's Scope, Sequence and Coordination project undoubtedly will require broad teacher preparation in order to succeed in doing anything other than redistributing traditional subject matter.

Unfortunately, there is no definitive research identifying an optimum level of content preparation for a new science teacher. Darling-Hammond (1991) and others have found that extensive subject-matter knowledge is not necessary, and may even be counterproductive. While under-prepared teachers tend to teach from the text and are wary of procedures which threaten their control over the class, teachers with a very strong content background may be too teacher-centered and pedantic. Beyond the point at which the novice has a firm grasp on the subject matter, pedagogical knowledge appears to be more important than more content knowledge, at least as it is traditionally taught. What constitutes a "firm grasp" is unknown. At present, the best guide to adequate program content must be determined primarily from the experience of professionals who regularly work with beginners preparing to teach science.

Effect of National Standards on Institutions

Not all NCATE review procedures require institutions to submit their individual programs for review by specialty organizations such as NSTA. In an effort to reduce the number of individual institutional reviews it must make, NCATE offers options to states which will grant recognition, under certain conditions, to all institutions meeting the accreditation standards of that state. Under these options it is agreed that the standards of NSTA and other specialty organizations will be used in the development and review of state standards, but NSTA has no control over this process and does not review these programs unless an institution individually chooses to be evaluated.

Under other options, institutions individually submit their program portfolios to NSTA through NCATE, and an NSTA review board evaluates their compliance with the standards. Although compliance with specialty standards is not required in order for an education unit to receive NCATE accreditation, such compliance is noted and regularly published by NCATE. In addition, NSTA has recently begun to periodically list institutional programs in compliance with its science teacher education standards in *NSTA Reports!*

A number of factors seems particularly to affect the ability of institutions to meet the NSTA standards. Although space does not permit a thorough discussion of these factors, four of the most important are:

1. *State program requirements*. Special problems are created when states require broadfield programs or combinations of courses which do not conform to NSTA standards or definitions. Some institutions meet the minimal standards required by their state and have no incentive to go further. State program requirements tend to be weak when compared to NSTA recommendations.
2. *Lack of cohesiveness*. Science content and related coursework does not appear to be

planned to meet needs specific to teachers. The science departments appear to determine the standards, which may be no different from those required for other disciplinary majors. Cross-disciplinary perspectives or themes are rare.

3. *Lack of subject-specific pedagogy.* Both large and small colleges and universities may fail to provide significant science-education methodology. In extreme cases, there may be no apparent education related to science teaching at all, even in more generic professional courses.

4. *Lack of Science-Technology-Society (STS), historical or philosophical perspectives.* This is apparent in many programs, where traditional subject-specific content dominates the syllabi. Few institutions offer specific coursework in STS. Most include a brief introduction in their science methods course, if such a course is offered. STS is seldom a pervasive theme.

In view of the fact that immediate changes are not required for NCATE accreditation, it is professionally gratifying to find that institutions do, in fact, modify their programs to meet the NSTA standards, sometimes in major ways. Table 1 shows many of the changes reported by institutions during 1991 in response to the NSTA standards.

Certification and Accreditation

In arguing for the opening of Alaska's classrooms to uncertified teachers, Jarvis (1991) writes that "certification does not always guarantee a person can teach or should teach. You cannot gauge, predict, judge or otherwise evaluate human commitment, potential or drive" (p. B6). The misconception that certification is a guarantee is a common one. Leaving aside the argument that a person with commitment should be willing to make the effort to be professionally certified, the statement serves as a reminder that certification, and accreditation, are primarily vehicles through whichprofessions raise the average level of practice.

Every profession has incompetent practitioners, and no system of evaluation has yet been devised

Table 1

Summary of Reported Changes Made to Science Teacher Education Programs Due to NSTA/NCATE Standards, 1991.

UG:	Science syllabus revised to comply with standards
OC:	Added supplementary course requirements in biology and general science; added a bioethics course to requirements for biology majors (might have been created for this purpose).
KC:	Added a requirement for statistics for all students; added a science methods course for both the baccalaureate and post-baccalaureate programs.
AS:	Physics syllabi revised to include STS components. ASU is in complete compliance with the standards.
UD:	Has expanded its methods course to include added emphasis on safety and statistics. Requirements for supplementary science in the physics program has been increased from nine credits to full compliance.
UL:	UL has made extensive changes in its program to meet NSTA standards, specifically it has added requirements for a course in statistics and specific, strong computer science education; increased science content to 36 hours in major fields with all areas covered; increased requirements to meet all supplemental science requirements; and has upgraded mathematics to meet all requirements. A requirement for a course stressing the relations of science, technology and society was also added.
UWC:	Has made changes including the addition of a middle-school-oriented methods course and the upgrading of mathematics requirements.
UC:	Added a three hour science methods course and revamped education course structure to address areas of concern. Differential equations was added to physics requirements and methods was upgraded by addition of computer applications. A one-hour science and society course has been added as a requirement for all science teachers.
LC:	Appears to have added a secondary science methods course for science which addresses most of the cited problems.
NI:	Increased science requirement in physics by 6 hours; revamped science syllabus to clear up problems.
RF:	Increased its mathematics requirement for biology to meet standards.
AU:	Increased their science methods course from two to three units; now requires biochemistry for a chemistry teaching major and oceanography for earth science majors.
IT:	Increased credit for science methods course.
CS:	Increased supplemental coursework in biology and chemistry to move program from noncompliance to full compliance with a change in progress for physics.
NU:	Added a three-hour science methods course.
HC:	Updated geology syllabus reflecting more STS emphasis; added course with environmental emphasis.
SM:	Added physical chemistry and biochemistry to chemistry teaching requirements; added science to meet supplemental science standards for chemistry, earth science and physics; added physical oceanography to earth science teaching requirements; strengthened course requirements, mathematics and STS in physics program.
CS:	Revised science methods course to increase emphasis on safety and research issues.

which is not inherently unfair to that individual who might practice well without a formal education. In medicine, for example, there have been documented cases in which individuals without formal education have practiced successfully for years without a license. Yet there has been little public pressure to allow self-taught physicians to practice, nor are there serious subsequent efforts to weaken accreditation, certification and licensing standards in medicine. It seems generally agreed that medicine is better off with such standards than without them, and that individuals who seek to practice should "take the time to do it right." Perhaps if students died physically in classrooms as a result of ineffective practice, there would be much greater support for substantive professional certification and accreditation. To be effective, professional certification and accreditation and the legal process of licensing should be complementary. The basic professional science teacher certification offered by the National Science Teachers Association has since its inception been linked to the science teacher preparation standards used during the NCATE accreditation review process.

The same kind of linkage does not appear to be occurring on the national level for broader professional certification initiatives. The National Board for Professional Teaching Standards (1989), stating that certification should be based on what a teacher "should know and can do, rather than upon the means of acquiring such skill...," rejects any linkage between graduation from an NCATE-accredited institution and NBPTS certification, saying "...the case is weak for proceeding beyond what amounts to a liberal arts and sciences requirement." In taking this position, it argues that such linkage would "...mean becoming dependent upon another body whose standards it could not control."

Lack of unity between national certification and accreditation will certainly be harmful to efforts for professionalization. Standards are not just guides for practice, but are also reflections of professional cohesiveness and identity. The lack of cohesiveness found in teacher education by Goodlad (1991) is apparent in the NBPTS statement. If disagreements are apparent in the professional standards, then school districts, governmental agencies, legislators and the public will be forced to make their own decisions about which standards to follow, a process which will effectively remove control of subsequent decisions from the profession itself. By rejecting linkage to NCATE, the NBPTS is casting doubt upon the validity of its own standards.

Preparation programs do not just transmit overt skills and knowledge, they also transmit professional attitudes, values, and the kinds of covert knowledge and behavior which stem from the characteristics of the program itself. Weak programs might enable their students to meet basic professional certification standards, but they are unlikely to impart the professional attitudes needed for sustained reflective practice. Strong accreditation standards will have the effect of modifying or removing such programs, but only if certification and licensing are firmly linked to accreditation.

Summary

In the early 19th century, medical practitioners in this country were not required to have a formal medical background, and one of the arguments voiced by practicing physicians against requiring a college degree was that good medicine was an art rather than a science: good doctors are born and not made (Darling-Hammond, Gendler, & Wise, 1990). This same argument is heard in teaching today, and it is often teachers themselves who voice this opinion. Just as so many physicians of the 19th century could not imagine what medicine would become, so many educators today have not envisioned what education can be.

Properly drafted professional standards, developed and administered through the education community, have a great deal of potential for improving educational practice. Teacher educators should only be held accountable for the quality of new teachers when they, as a group, have been given control over the conditions of preparation. By separating government from certification and accreditation, responsibility will shift to those who are in the best position to regulate entry into the profession. The role of the state will be to ensure accountability, rather than to control professional affairs directly.

Although the NSTA science teacher education standards have been rightfully criticized for their shortcomings, this does not negate the need for standards. New national science standards are now being developed under the leadership of the National Academy of Sciences, the National Research Council's Coordinating Committee. Although NSTA and the Association for the Education of Teachers in Science are seeking input into this effort, there is substantial evidence that this is a top-down effort undertaken in response to political concerns, including the desire to be the best in the world in science by the year 2000. Because they may ultimately be used for such things as funding decisions, these standards will undoubtedly be influential. Whether or not this influence stems from a research base and best professional practice remains to be seen. The articulation between these and other standards, including the current NSTA/NCATE standards, will also be important.

In the near future, a number of steps should be taken to ensure that the science education community continues to have a voice in the process of professional accreditation:

1. NCATE must recognize and fully respect the role of the specialty organizations such as NSTA in setting and implementing standards;
2. Standards must be developed which recognize the real needs of school districts and innovative curricula, including any compromises that entail;
3. Standards must be developed according to the best available knowledge base, rather than a philosophical ideal;
4. Flexible standards must be developed for both process and outcome (since all outcomes are not measurable);
5. Accreditation, certification and licensing must be consistent, founded on well-reasoned philosophies and a common knowledge base;
6. Educators at all levels must recognize the need for theory and reflection as well as practical education for new teachers, because it is only through these valuable characteristics that the profession will progress.

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The "New Elegant Solution" for Science Teacher Preparation and Development: A California Story of Systems and Connections

Bonnie J. Brunkhorst

Science teaching preparation is now recognized as a pivotal influence in the reform of science education. Approximately 10 percent of the nation's teachers are prepared by the California State University System. TRIADS of scientists, science educators, and lead teachers, K-12, from each of the 20 CSU campuses are collaboratively addressing reforms for preparing teachers who can respond to the new science education needs. Other state systems are coordinating their efforts in cooperation with the CSU Science Teaching Development Project, coordinated at CSUSB. The "Elegant Solution" requires the collaboration of the systems that affect the preparation of new teachers of science.

Elegant Solutions

A Sidney Harris cartoon, published in "American Scientist" and recently reprinted by AAAS (AAAS, 1992), shows two forlorn-looking scientists in front of three walls of blackboard filled with a multitude of equations, one saying, "Whatever happened to elegant solutions?"

"Elegant solutions" are not being found using a simple, linear approach. Isolated, controlled variables taken out of the context in which they function, adjusted and returned, are not producing the simple solutions the science education community had hoped for in the past. Our collective experiences, both academic and social, indicate a need to examine systems within their total context, simultaneously exploring the multitude of variables that together affect the nature and function of the whole in which they exist. New visions, new solutions, both academic and social, must often be holistic and systemic, reflecting the systems that affect them and the systems in which they exist. Such is the case for science education, and science teacher education.

Science Education in Context of Society

Science education is now being viewed by our society as an element essential to the health of our nation. George Gallup notes that "Americans think nothing more important for the next 25 years than having the best education system in the world. Education has become the national worry," (Alexander, 1992, p. 1). The fourth of six of our "National Education Goals" highlights science education: "U.S. students will be first in the world in science and mathematics achievement" (U.S. DOE, 1991, p. 9). Scientific literacy, the product of our science education systems, does not stand isolated from other indicators of our national health. Likewise, the systems that effect science education are being examined in light of how they simultaneously and collectively affect scientific literacy. As the systems of national science standards, curriculum reconfiguration, school restructuring, national, state, community and family resources, assessment, and so forth, are being restructured, so too must the preparation and professional development of teachers who teach science in our schools be revisited and reconceived in service to the vision of scientific literacy for all. Science teacher preparation (preservice) and development (continuing inservice) need a new vigor, a new vision, placing it in the context of the restructuring of science education. The "elegant solution" to improve science teaching must of necessity be holistic.

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Science Teacher Preparation in the Context of Science Education

John Goodlad (1991) placed his vision for teacher education in the context of Whitehead's call for adventure beyond the safeties of the past:

> A race preserves its vigor so long as it harbours a real contrast between what has been and what may be, and so long as it is nerved by the vigor to adventure beyond the safeties of the past. Without adventure, civilization is in full decay. (Whitehead, 1933, p. 360)

The necessity for change related to new visions is problematic for many. The need for change is rooted, however, in the fact that the verities of the past are changing. The USSR is no more. South African apartheid is gone. World economics are adjusting. America's big industrial complex is dispersing. America's demographics are shifting rapidly. The information age is here. America's children need more services now and new skills for the future.

The educational enterprise exists in the midst of a world in flux, indeed is a system of that world. Assuming that education is to optimize human life in this world, it follows that education must also be in flux. New visions are not being met by old practices. Out of necessity, educational systems must be reinvented to welcome the opportunity for new vision and new practice to meet the needs for quality life in the new world.

Science education stands at the intersection between scientific and educational communities. The science education enterprise must address the goal of scientific literacy for all by paying attention to the rapidly evolving interdisciplinary connections of technology, information management, and social implications, and the building imperative for educational change to prepare citizens for success in the twenty-first century. Teachers must be prepared to address the new goals of science education.

Science education in the nation's schools is being reconceptualized:

> Reform is needed because the nation has not yet acted decisively enough in preparing young people, especially minority children, on whom the nation's future is coming to depend for a world that continues to change radically in response to the rapid growth of scientific knowledge and technological power. (AAAS, 1989, p. 3)

A multitude of reports from many communities, scientific (National Research Council, 1990), education (ASCD, 1992), science education (AETS, 1991), government (U.S. Department of Education, 1991), private foundations (Carnegie Commission, 1991), and the media indicate trouble. The breadth of concern indicates the nature of the systems affecting the science education enterprise. Each system has contributed significant and overlapping recommendations to the reconceptualization. A growing national consensus has emerged centered on the premise that "schools do not need to be asked to teach more and more, but to teach less, so that it can be taught better" (AAAS, 1989, p. 3).

A nationally defined set of new quality indicators for science education is emerging. The National Academy of Science, in cooperation with the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), a number of other science and science education societies, and with support from the National Science Foundation (NSF) and the U.S. Department of Education (USDOEd), will be producing hallmark descriptions of national standards for K-12 science curriculum (i.e., "what students should know and be able to do"), science teaching, and science assessment.

Science teaching and learning is an essential system in the reconceptualization of science education. It is a simple but elusive truth that any restructuring requires new skills and the enhancement of existing skills for those who implement the new practice. Enhancing existing skills suggests modes of "staff development programs." Producing new science teachers able to serve the restructured model of science education requires a reconfiguration of preservice programs that connect with inservice teachers such that new skills can be developed continuously for both new and experienced teachers. Thus science teacher education must be viewed as a continuum from preservice to staff development programs. The concept of "professional development" as a connected system of preservice and staff development is the foundation of the emerging California "elegant solution" for new science teacher preparation.

California Systemic Science Education Reform

California science education reform fosters a statewide alignment of all the systems affecting science education, simultaneously and cooperatively working toward implementing the national and state quality indicators of science literacy for all citizens (AAAS, 1989; CDE, 1990). Emphasis in this reform is placed on content in the context of how science is used, breadth as well as depth of knowledge, development of genuine personal understanding, connections among the sciences (NSTA, 1992), and science as a way of knowing (CDE, 1990). The California systemic approach to restructuring science education, coordinated by the California Department of Education (CDE), Tom Sachse, Manager for Science, recognizes the need to redirect all of the systems to support change. These systems to be re-directed include teacher leadership and professional development, school administrative partnerships, California Department of Education (CDE) efforts, California Commission on Teacher Credentialing (CTC) efforts, assessment systems and university systems, among others.

The California State University (CSU) system of twenty universities, by state mandate, carries the responsibility for "Education" in the state's higher education plan. The CSU also produces the vast majority of the state's teachers. The CSU, through the SS&C Preservice Project, has begun to address its responsibility for leadership in restructuring science teaching development in service to the restructuring of science education in California. Teacher education is one of the systems in the reform enterprise.

Science Teacher Development in California

> Providing leadership means constructing a vision. Visions are not statements of the status quo, they are new, they are substantial, and they look to the future. (Bybee, 1992, p. 3)

Placing the responsibility for science teacher education in-service to the restructuring of science education in California squarely on the shoulders of the university system that produces most of the state's teachers required a shared vision for improving science education and the CSU's role in that enterprise. Visions are not effective if prescribed, especially in universities where academic freedom is protected as essential to democracy. Developing a shared vision for service to the CSU's science education mission for each university's geographic "service area" was an early step in the Preservice Project. Essential to the vision is the contextual perspective of educating teachers (pre- and inservice) who can be the professional practitioners and leaders for the reforms in California school science. Connecting with all the systems involved in the reform is necessary to the holistic view of teacher education as part of the reform. Communication is the basis for developing the vision.

Communication for Vision

The Institute for Science Education (ISE) at California State University, San Bernardino (CSUSB), assumed responsibility for coordinating the CSU role in science teaching education as a component of the California Scope, Sequence and Coordination (SS&C) Project (California "100 Schools"). The California SS&C Preservice Project is co-directed by Herbert K. Brunkhorst, Director of the ISE, and Bonnie J. Brunkhorst, Associate Director of the ISE, and Chair, Council of Scientific Society Presidents.

Teaching SS&C requires the development and practice of new skills, new knowledge, and new attitudes toward science teaching. New skills include management and teaching strategies facilitating the development of students' deep understandings of science themes, concepts, and interpersonal collegial skills. New knowledge includes connections and themes among the sciences, pedagogical knowledge, curriculum resources, developmental and cognitive psychology. New attitudes include commitment to continuous learning, change as opportunity, willingness to forge new paths and make new connections, and interest in making science a successful experience for all learners.

The CSU Deans of Education and Deans of Natural Sciences extended invitations to the Brunkhorsts to present the nature of the science education reform and the prospective CSU role in the reform. Deans' representatives (Science and Education from all twenty CSU campuses began a series of bimonthly, statewide meetings, alternating in the north and south. Science faculty, science education faculty, and other education specialists from the campuses met together to explore the need for the reforms. These meetings established the TRIAD relationships.

TRIAD Communication

The "systems" principle for reform extends deeply into the conceptualization of the California SS&C Preservice Project. A "TRIAD" of collegial leadership for each university is based on co-equal interaction from three areas of expertise: university scientists, science educators, and SS&C reform teachers (see Sachse's article in this issue of the *Review*.) in the university's geographic "service area". Each university, encouraged by the CSU Preservice Project, has developed a TRIAD of various configurations, some new, some existing, to serve teacher preservice and inservice needs in support of the SS&C reform throughout the state. In the more sparsely settled areas of California where SS&C schools are not in commuting distance of a CSU campus, the campus assumes a facilitative role for its local schools to reevaluate their science programs in light of state and national reforms, connecting with the state networking for SS&C through the university.

TRIADS meet together in statewide CSU SS&C Preservice Project meetings. Teacher-leaders (SS&C Hub Coordinators) help university scientists and science educators to understand their needs and potential contributions to the university science and science teacher education programs. Scientists help teachers understand their interest in cooperation and assistance to SS&C needs, focusing on content in preservice and inservice. Science educators help to facilitate the many connections and resources, the research base, issues and misconceptions among the systems, in addition to their responsibilities for the professional "fifth-year" component of teacher credential programs. Communication and trust among the TRIAD members based on a shared vision is basic to the Preservice Project.

CSU/STDP Network Development

When the university scientists, in discussion, identified a need to improve their undergraduate science courses to contribute to the science education reform (secondary SS&C and elementary science teaching), the leaders knew they were on the right "constructivist" path. (Constructivism being the research-based contributions from psychology, education, and science education which allow learners to "construct" their own meaning from experiences.) We knew ongoing commitment and the development of new science teaching programs on each campus required genuine, mutual collaboration in the TRIAD and throughout the CSU system. When the scientists requested help with their own teaching strategies from the SS&C teachers, we knew we were reaching a major goal: commitment to reform, communication, trust, and respect for each others' differing areas of expertise. When the teachers sought an ongoing relationship with their local CSU scientists and science educators for help with content and pedagogy, we knew the "Preservice Project" was up and running.

Bringing the university system together with the reforming schools through the placement of SS&C-prepared student teachers was identified as the ongoing "umbilical cord" between the CSU and the reforming schools. Reconfiguration of the university programs for science teaching preparation, undergraduate science, professional 5th-year credential programs, and ongoing inservice support to area schools, has become the vision of the CSU as a part of the California science education reform. Working in collaboration with various colleagues with differing areas of expertise has become the means toward that vision.

To facilitate and institutionalize the CSU-wide TRIAD collaboration, the CSU Science Teaching Development Project (CSU/STDP) has been established, and has been funded by the National Science Foundation (NSF), as an outgrowth of the California SS&C Preservice Project. The primary focus of the CSU/STDP is to prepare and support K-12 teachers for the reforms in science teaching by using TRIADS of scientists, science educators, and exemplary teachers. The CSU/STDP extends to elementary science teachers through the California Science Implementation Network (CSIN). Empowerment of each CSU campus to institutionalize its local efforts to support reform is basic to the project.

Elements of the CSU Preservice Project Exploration

The American Chemical Society (1991), adding its voice for reforms in science education, indicated problem areas in a recent statement:

> ... inadequate preparation of precollege teachers in terms of subject matter knowledge; lack of professional development opportunities.

The Carnegie Forum's Task Force (1986) in Teaching as a Profession stated that:

> Teachers need a command of the subjects they teach, a sound grasp of the techniques of teaching those subjects, information about research on teaching, and understanding of childrens' growth and development of their different needs and learning styles...Arts and science faculty must join their education colleagues, and ...begin by undertaking a review of the undergraduate curriculum for the education of prospective teachers. This does not call for a "watered-down" curriculum, but a strengthened one. (p. 72)

Later, the report continues, "'Clinical' schools, selected from among public schools and staffed for the preparation of teachers, must be developed to make this successful" (Carnegie, 1986).

The CSU Preservice Project addresses all these areas as they relate to the preparation and support of SS&C science teachers, by questioning implied models of thinking. Special focus is on the professional leadership of teachers who function as change agents with the support of their local university's systems through preservice and ongoing inservice in content and pedagogy. A significant goal is the placement of the universities' SS&C-prepared science student teachers in area SS&C schools for their student teaching experience.

The CSU Project is exploring the questions related to "SS&C-prepared teachers" in terms of California's undergraduate science requirements, the fifth-year professional credential program including student teaching, and ongoing inservice for area SS&C schools, especially those who receive the universities' student teachers. The exploration includes state and university requirements as well as local opportunities and constraints. All 20 universities are exploring their current programs with various stages of planning and implementation of SS&C supportive programs. Most have prepared initial campus-specific reports on their "actual" and "desired-state" programs relative to SS&C preparation.

The CSU Preservice Project dialogue has also resulted in suggestions including (a) sharing SS&C-based secondary curricula among CSU campuses, (b) means for strengthening university support for the SS&C philosophy, (c) providing a more coherent teacher preparation program including both scientists and science educators, (d) clustering science student teachers in SS&C schools, (e) moving toward team teaching by master teachers in SS&C schools, (f) finding solutions of inconsistencies between school and campus schedules that negatively impact science student teacher preparation, (g) providing materials that exhibit integrated/coordinated science curricula, (h) jointly establishing good models of science teaching at all levels, (i) identifying what it is that "good science teachers" need to know, (j) encouraging community service for university science majors in schools that are restructuring their science programs, (k) exposing university undergraduate science majors to coordinated science, and (l) developing programs for teachers using reform-based science teaching as an incentive for taking greater leadership in science education" (Brunkhorst, 1991).

The San Bernardino Model: "Practicing What You Preach"

In response to the goal of developing a professional development school (i.e., "clinical" school model) appropriate for preparing and supporting SS&C-capable teachers, California State University, San Bernardino (CSUSB) has been experimenting for the past two years with a collaborative cluster model, developed by Herbert Brunkhorst.

The first cluster of CSUSB science student teachers have just completed their high school student teaching in an SS&C school (Etiwanda High School, Chaffey Union High School District, Tim Ritter, Science Chair and SS&C Hub VIII coordinator; Herbert Brunkhorst, CSUSB, Professor). Clustering places a cohort group of student teachers with a group of practicing SS&C teachers, establishing a professional community of master and novice science teachers functioning as collegial change agents for the SS&C reforms. The arrangement allows preservice teachers to experience teaching in their undergraduate science major (e.g., chemistry), teaching in an SS&C-coordinated science class, and an opportunity to assist a master teacher in an area of science in which they are weak (e.g., physics for a biology major). The model also allows master teachers an opportunity for onsite, school-day, university inservice for content and for pedagogy. An ongoing relationship among CSUSB science faculty, science education faculty and Etiwanda High School's science department is building using the natural "umbilical cord" of university science student teacher placement. CSUSB science faculty from biology, chemistry, geology, and physics have met with the Hub VIII schools (SS&C schools in the Inland Empire) to establish their collegial availability for content assistance as determined by the teachers as they work to teach coordinated science. Making these ongoing connections in each CSU service area throughout California is one of the goals of the CSU Preservice Project. The Etiwanda science department is to be congratulated for its professional leadership, not only in teaching coordinated science, but for establishing collegial relationships with novice teachers during their student teaching experiences. The six new "SS&C-able" science teachers have solid experiences as change agents prepared for leadership in their profession.

Goals and Process for the CSU Preservice Project

The California SS&C Preservice Project has established the CSU Science Teaching Development Project (CSU/STDP) to begin coordinating and supporting restructuring of university science teaching programs throughout the state. Three general goals are being addressed:

1. placing CSU preservice programs for both content and pedagogy in support of SS&C restructuring in each university's geographic service area;
2. preparing science teachers who can teach in the SS&C reform, serving as ongoing agents for change in their profession;
3. focusing the CSU state-mandated responsibility for "Education" on the CSU leadership role for science teaching development for California.

The processes being used to approach these goals include the development of the CSU/STDP Network, addressing the goals on each campus with support of the Network for: 1) the professional fifth-year programs, including student teaching; 2) undergraduate science (waiver programs); 3) providing SS&C teacher support with content and pedagogy; 4) credentialing process; 5) university admission requirements; and 6) science assessment systems. Recognition of the need for each campus to develop its own appropriate programs for supporting science teacher preparation and inservice, and understanding the power of mutual support through system-wide action is paramount.

Accomplishments of the CSU Preservice Project

All 20 of the California State Universities, that is the universities that prepare the majority of the state's teachers, are committed to cooperation. All are exploring changes in their waiver programs, undergraduate science courses, professional programs and student teaching placement. All value the TRIAD communication among university science, science education faculty, and school science faculty. Most of the campuses have science methods courses that stress the California Framework, and the coordination of science espoused in SS&C and AAAS' Project 2061. Most have specific plans for student teacher placement in SS&C schools. Most are planning or implementing SS&C Curriculum Resource Centers (NSF funding pending). Most have active TRIAD communication and are connecting other funded projects with SS&C goals. Unique models for science education reform are developing from individual campuses. The Preservice Project provides a forum for sharing of ideas, possibilities, problems and solutions.

The Future

The "elegant solution" for science teacher education is a story of California systems and connections working together to address reforms aimed at making scientific literacy a reality for all of California's citizens. The SS&C Preservice Project has spawned a statewide university network for improving science teaching development programs in California. Support from the State Department of Education, the California Commission on Teacher Credentialing, the CSU Chancellor's Office, the California Council on Science and Technology, and funding by the National Science Foundation, have helped to foster the development of a model holistic, evolutionary, collegial "elegant solution" for the issues surrounding the preparation of science teachers for the new demands on science education in California. Extension of the Network to the University of California campuses, the

California Community Colleges, and private universities is planned. The door is open for cooperation. The future is encouraging.

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Scientific Literacy: Extending Connections Through Science, Mathematics, & Technology

Mary Hamm

Scientific literacy includes the many disciplines of science, mathematics and technology. Although such literacy has emerged as a major theme in American educational reform, it remains an illusive goal. Numerous studies have made it clear that U.S. education is failing too many students in this area–and thus failing the country. Many students complete their educational experience and will be, for practical purposes, scientifically illiterate, unprepared to participate in a science and technology-oriented society. Part of the answer to achieving scientific literacy lies in teaching for deeper understanding, helping students to relate school concepts to everyday life, using hands-on examples, and connecting ideas across disciplines.

Many complain that students simply do not make meaningful connections with science, mathematics and technology. Researchers have found that students often have a very superficial understanding of what they have been taught in science and mathematics (Perkins & Simmons, 1988). Studies reveal that even college students who have had formal instruction in physics frequently do not understand what Newton's laws really say about the way objects move (McCloskey, 1983; Clement, 1982, 1983). Many younger students have only a vague sense of the size of a fraction: they have trouble placing fractions on a number line, and have difficulty recognizing equivalence (e.g., 3/12 is the same as 1/4) (Behr, Lesh, Post, & Silver, 1983).

The question of how elementary school classrooms can meet these concerns is being grappled with in the Department of Elementary Education at San Francisco State University (SFSU). Recently an experimental course section in mathematics, science and technology was offered for the Clinical Schools Project (CSP). In this project, 32 student interns were placed in elementary school classrooms where they observed and taught lessons under the supervision of a master teacher. The project offers an opportunity to explore interdisciplinary learning and teaching and its transfer by teacher candidates in the elementary classroom. This paper discusses the university course, the teacher candidate response, and the effect of what they learned upon their teaching.

Changing the Image

A new pattern for teaching mathematics and science is emerging which focuses on the nature of learning rather than on the content or method of instruction. It emphasizes relationships and views science and mathematics as a process or a journey. Today's focus is on how to motivate students for life long learning of science and mathematics, how to awaken curiosity and encourage creativity, rather than how to answer questions correctly or memorize facts. Students are encouraged to relate and apply science to social problems, to mathematics, to technology, to creative innovation, and to their personal lives.

In the latest approaches science and mathematics are seen as touching people, caring for the planet, and becoming knowledgeable and socially responsible citizens. Today's best science and mathematics teaching emphasizes inquiry and builds on students' understandings and misunderstand-

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ings. A priority is given to improving the student's self image; self concept is viewed an indication of performance. Some of the newest methods for teaching science and mathematics include techniques such as: creative visualization or mental imagery, keeping daily logs or journals, and expressing attitudes through creative endeavors such as writing, building or art. Holistic creative thinking is encouraged as well as projects and presentations that combining experiential knowledge with theoretical understandings. Emphasis is on exciting examples and everyday applications. The student is a participant and an explorer.

Contemporary mathematics recommendations have suggested a broader curriculum including estimation skills, problem solving, practical geometry, statistics, data analysis, calculator skills, probability, measurement and patterns. The disconnection of mathematics and science to other subjects, from history to sports, is another problem. Civic, leisure and cultural features of numeracy and science are rarely discussed or developed in school. All too often math and science are taught as a separate set of skills needed for the next academic level.

Today's students need opportunities to make connections and to work with peers on interesting problems. They also need to be able to apply the skills they are learning to real-life situations. Computational skills, the ability to express basic mathematical understandings, to estimate confidently, and check the reasonableness of estimates are part of what it means to be scientifically literate, numerate, and employable.

Examining Learning

Problems in learning mathematics and science are the major reasons why students to fail in school. Much of the failure is due to a tradition of teaching that doesn't match the way students learn. Cognitive psychologists, such as Piaget and Bruner, explained long ago how students construct understandings based on their own experiences and that each individual's knowledge of math and science is personal (Bruner & Haste, 1987). No wonder that computing, listening, and memorizing abstract concepts or symbolic procedures leave a bad taste for the subject.

The true goals of mathematics and science education should be to help students learn how to apply knowledge, solve problems and promote conceptual understanding. Students need to be able to use science processes to change their own theories and beliefs in ways that are personally meaningful and consistent with scientific explanations. This way they can develop conceptual understanding and the means for integrating science knowledge into their personal conceptions.

To really learn science and math, students must construct their own understandings, examine, represent, solve, transform, apply, prove, and communicate. This happens most effectively when they work together in groups to discuss, make presentations, and create their own theories (Hamm & Adams, 1992). Such an environment encourages students to engage in a great deal of invention as they impose their interpretation on what is presented and create theories that make sense to them. Learning about science and mathematics also involves learning to think critically and create relationships. How these relationships are structured in a student's mind depends on such factors as maturity, physical experience, and social interactions. The ability to inquire, collaborate and investigate fuels personal autonomy and self direction in learning. The inability to do these things (scientific illiteracy) leads to inequality of opportunity, weakens our capacity for productive competition, and undermines American civic culture.

Engaging Learners in Science/Math/Technology

Piaget (Piaget, 1986) claimed that learners must construct their own knowledge and assimilate new experiences in ways that make sense to them. What is the role of teaching if knowledge must be constructed by each individual? Because the course was concerned with the process of teaching and learning science, mathematics and technology, interns were engaged in active participation. Eleanor Duckworth (1987) wrote that it is important to have prospective teachers examine their own process of learning, and to put them in the position of constructing and examining their own knowledge about math and science phenomena–to actively engage them so they will continue to think and wonder about it. The challenge, for the instructor of this course, was to make these active experiences different and interesting enough to arouse the interns' curiosity and to inspire them to ask questions they hadn't thought to ask before. The goals of the experimental course were to have teacher candidates:

1. develop a greater understanding of the role of content knowledge in problem solving;
2. recognize the need to take into account the personally constructed understandings that students bring to learning situations;
3. become aware of the need not only to assist students in processing, structuring, and restructuring ideas, but also to make them metacognitively aware of their actions, thoughts, and ideas; and
4. work cooperatively to plan and teach lessons to elementary students across science, mathematics, and technology disciplinary lines.

As part of their day to day assignments (on the assigned topics for investigation), students were instructed to bring in science and mathematics activities, and examples of science and math problems from their readings, videos, and observations in their classrooms.

Students objected to the required participation. One student explained she was so tired after being in a second grade classroom for four hours she just wanted to listen to a lecture. Another explained that she had always had difficulty with science and mathematics and was very unsure of herself in these areas. Some student comments included how they perceived their knowledge of math and science before this course and how their ideas had grown or changed during the semester. The following excerpts are taken from reflective accounts that students wrote *late* in the semester.

> Because I did not find math and science a very interesting and fun area in my own years in school. I did not think I would get into this area much, but after our work I found some pleasant surprises. –Lee

> Beginning the semester I believed that I didn't like math or science and wasn't skilled in it. I believed that some people have an aptitude in this area, and I was not one one them. Now, I believe that with the right teaching techniques, everyone has an aptitude for math and science. I also believed that I would never be a very effective math teacher, and I do not believe that at all. –Lara

> Math and science have always been subjects that I have the most confidence in. Prior to this course I could think of no way to teach these subjects (especially math) except by using a teacher directed method. I pictured myself standing up in front of the room and lecturing the students in the same boring manner that I was taught. This course has shown me that any subject can be fun, and taught in such a way that anyone can learn it. Even those who "hate" math.–Erin

> I never enjoyed math or science in school and was not looking forward to this class with much enthusiasm, as I thought it would be boring and difficult, like science and math were for me as a kid. I can't emphasize, however, how refreshing and exciting this class was for me. I kept saying to myself, "If I had been taught the way I'm learning to teach, I would have loved math and science!" –Samantha

> I was under the misconception that math and science were dry subjects full of facts that you had to memorize but did not understand why and thus very boring. After taking chemistry and calculus in college, I was at the point where I would ask myself constantly "Why do I need to know this?" –Walley

> Before entering the math, science and technology class, my understandings of the subjects were unclear and basically, when mentioned these three words engendered fear due to lack of knowledge Now that I have completed the course my insight and understandings of the topics have developed, allowing me to feel comfortable and unthreatened. –Lillian

Making Sense Communicating

As a part of the cooperative learning strategy in "Teaching Science, Math, and Technology in the Elementary School," student interns were asked to try to make sense of what they were thinking and explain it to others. Obviously, in that process it was as necessary for them to try to understand the explanations that others were offering, to seek out more examples and explorations. Using portfolio assessment as a part of the project evaluation, SFSU researchers collected documentation about the progress of each participant. As but one example of the collected data of participants' self-assessment of learning, following are some responses to the portfolio assessment question: "How have your experiences this semester helped you understand the learning process?"

> Overall I would have to say that as I was writing and thinking about the questions, I learned a lot more than I thought. A lot of my understanding comes from the in-class activities and the use and importance of manipulatives. I'm a hands on person myself. I also mustered up the courage to ask the question, "why?" I realized that I wasn't the only one who had difficulties with the subject. I felt relieved after the realization and put forth a lot of effort wanting to learn as much as I could. I now feel as if the effort paid off and the knowledge is a great reward.–Arlene

> From doing activities in EED 677, I also learned or relearned, facts about math and science that I don't remember knowing about. I don't remember how I was taught math and science in elementary school. All I know is that I was good in math, but I don't remember why. I feel like the activities I learned in EED 677 made science and math memorable. When we studied about the universe, I never realized how much I didn't know. but by the time we were done with the activities I felt I had a good solid knowledge about how the universe worked.–Michelle

> I think there's only a small percentage of students in our particular class that did not learn something significant from the astronomy visit and learning activities by the groups regarding the rotation of the earth and the effects of the tilt of the axis on the seasons on earth. Even in class someone remarked to me they thought the same as the Harvard students in the video. By the way would you write me a note saying the the seasons are not affected by the rotation of the earth around the sun. I asked everyone I knew at any subsequent gatherings the same question that was posed to the Harvard grads and my nephew insists that there is a more than slight elliptical rotation of the earth, that the rotation affects the intensity of the seasons. (This dogmatic retaining of schema reminds me of that 5th grade blond girl on the videotape.)–Lillian

> I feel more confident and interested in these subjects. I believe that I have a great deal of options... The activities that we both brought into this class and presented were of great help to me. I picked up a lot of information which I was able to convey to my students. The whole idea that there are many different ways to do a problem was so important for me to learn. I feel that my own way of learning was validated in my classes and their ways of learning. –Lorena

> ...from learning so much new material, I found myself conjuring up conversation just so I could "show off" my knowledge of the subject. For example: my mother and I were in the car and I pointed out how big, bright and close the moon appeared that evening. My mother replied with "Yes, it is I wonder why?" Then, of course I started rambling off the reasons for the appearance. My mother looked at me as if to say how do you know that? I told her about all of the various activities and the story regarding the moon phases.– Arlene

> My attitudes, beliefs, and personal confidence has all been changed this semester. I feel a lot more comfortable with math, sci-

ence and technology. Science was always like such a large topic... The use of video in the classroom was such a surprise to me. I learned so much; the use of muting the sound, stopping the video to ask questions,... I learned about different math and science manipulatives, and how to use them with students.–Hillary

A third kind of experience in this class was to learn as a group and devise ways to teach this information to students in their elementary class placements. Thus, interns were required to try out activities of their university course with their own elementary students. Again, teacher candidates were asked to reflect on their teaching competence and include samples that supported their statements. Here is a brief sampling of their responses.

> An example of how I have used my new knowledge is when my partner and myself came up with a unit on air. We used many of the examples we had tried in class. The class was a third grade, and we were able to teach these children complex ideas that I never dreamed young children could grasp. Some of the concepts were: dew point, condensation, and how fog is made. If I had lectured these children they would have stopped listening during the introduction. But I used many teaching ideas I have learned in class. One that I am really proud of was a lesson on how fog is made. Children had to get the ideas that air molecules pick up water molecules, then when the air reaches its dew point the air molecules release the water molecules producing fog. I was able to successfully get the children to understand this concept by role playing. The entire class became air molecules traveling from Hawaii to the coast of California.–Diane

> The content of material learned regarding the universe persuaded me to do my teaching unit on the solar system. This decision stifled me because throughout all my years learning of the subject it still remained unclear as to what revolved around what and what rotated around what! During the course of writing and discussing and watching I finally realized that for the first time my general knowledge of the subject was intact. I also felt as if I could actually teach the subject without being careless. –Jo

> It is very exciting to see the students interested in the activities.–Eric

> Hands on activities are meaningful for students. I was really jazzed when I saw every student involved in a lesson. Working on the unit was a very rewarding experience. I have learned a lot about aerodynamics and I got excited about the process of creating a unit that would appeal to students and teaching them in a way that is exciting and creative.–Lynn

> I really impressed with the estimation skills of my second grade class. We sized things up and down, spatially and numerically.
> –Jodi

The above results from final portfolio assessments of student interns' progress show improvements in their confidence in mathematics and science teaching. This study also adds support to a growing body of research on effective practices in teacher development programs. Bearlin and Elvin (1988) have suggested that effective practice should: focus on children's learning, provide experiences of small group collaborative problem solving in a non-threatening environment, and place learners at the center and encourage them to talk about and reflect on their own learning.

People have always been concerned with transmitting attitudes, shared values, and ways of thinking to the next generation. Today it seems more critical as every part of contemporary life is bombarded by science and technology. Part of scientific literacy consists of clarifying attitudes, possessing certain scientific values, and making informed judgments. Students need to cultivate scientific patterns of thinking, logical reasoning, curiosity, an openness to new ideas, and skepticism in evaluating claims and arguments.

Positive attitudes are also important. Being able to understand the basic principles of science, being "numerate" in dealing with quantitative matters, thinking critically, measuring accurately, using ordinary tools of science and mathematics (including calculators and computers) are all part of the scientific literacy equation.

When teachers transform the limited and schematic conceptions of science and mathematics programs into the kinds of activities that genuinely engage students, they create learning environments that open up new avenues and provide for deep satisfaction. This can make a difference in the lives that children lead.

Tomorrow will bring different solutions to the best that we can envision today. Consequently, innovation and planning must occur without too many preconceived notions. Once programs are in place new pictures emerge and programs will have to change with changing social and individual needs. Whatever new realities fall into place to change our views, there is no reason why scientific literacy cannot be achieved by all students in the United States. It's a matter of national commitment, determination, and a willingness to collaborate towards common goals.

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Issues in Assessment: Purpose, Alternative Assessment and Equity

Angelo Collins

In discussions of assessment, whether the focus is on student science at the classroom, the state or the national level, three recurring issues emerge: purpose, alternative assessment and equity. Here aspects of these issues are examined through three questions, "In what ways do differing purposes for assessment influence the mode of the assessment?" "What is known about some alternative modes of assessment available for science?" "What questions need to be addressed to indicate that equity is a serious concern?"

Students and their parents frequently equate assessment with tests and grades, but members of two other groups concerned with science education–policy makers, including state and local education administrators, and classroom science teachers–claim that assessment is the process of gathering data in order to describe what students are learning.[1] Raizen et al. (1989) identify four general purposes for gathering data to describe student science learning: improvement, conveying expectations, monitoring status and accountability. Even as administrators and teachers agree on these purposes, their focus is necessarily different; for example, while administrators are concerned with the improvement of state and district science programs, teachers are concerned with improving instruction; while administrators convey their expectations to other administrators and teachers, teachers convey their expectations, and those of administrators, to parents and students.

Because state-level administrators are ultimately responsible for the educational quality of the state, their assessment concerns often focus on the closely related issues of status (how well we teach science to the students of the state and how we compare with other states), monitoring (how well each district implements state curriculum guidelines) and accountability (the effect of the money spent on science teaching). As may be expected, science teachers are more concerned with individual students entrusted to their care and with diagnosing, monitoring and improving the science learning and teaching of these students than with issues of relative status. The major dichotomy between these differing purposes (i.e., assessment for accountability and assessment for instruction) influence the mode of assessment utilized; therefore, some characteristics, examples and implications for the assessments traditionally used for each purpose need to be considered.

External Assessments

State-level assessments, alternatively called external, externally mandated, and/or assessments for measurement (Haertel, 1991) are practical and affordable means of monitoring large numbers of students, the target group for state-level assessment. They are intended to be used relatively infrequently (e.g., once a year) with these large groups. These assessments, usually in the form of standardized multiple-choice tests, provide data that are psychometrically reliable, with well-documented limits to their validity and potential for bias. Such tests are relatively inexpensive of time and money to design, administer and score. The scores are norm-referenced and can be reported to both the education community and the public in

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forms that are familiar and understandable.

Despite the continued discussion by the president, Congress, and the National Governor's Association of a national "Test of Academic Excellence," at this time there exist only three major forms of external assessment available to state level science educators: (a) the National Assessment of Educational Progress (NAEP); (b) commercially developed, nationally normed examinations; and (c) examinations developed by individual states.

The NAEP was designed in 1969 in response to a congressional mandate to track educational achievement and trends across time and/or school subject. The original intention for the NAEP was that data on an individual student, school, district, or state would not be available. Thus, comparisons could not be made. In addition, data were reported in terms of proficiency levels rather than performance standards. However, in 1990, 37 states (and three territories) responded to an NAEP request to supplement eighth grade mathematics samples so state comparisons could be made. In 1992, data were expanded to include comparisons of fourth grade mathematics and reading achievement. Also in 1990, performance standards in mathematics replaced proficiency levels and it is intended that performance standards will be developed for all school subject areas. Therefore, it is becoming possible to use NAEP data both to compare achievement of groups of students in one state or district with another and to compare groups of students against standards (Hudson, 1991).

Commercially Developed Tests. Currently, six major, commercially developed external tests are used to assess science teaching and learning: the Comprehensive Test of Basic Skills (CTBS), the California Achievement Test (CAT), the Iowa Test of Basic Skills (ITBS), the Iowa Test of Educational Development (ITED), and the Metropolitan and Stanford Achievement Tests. In a 1990 survey, 16 states reported using one of these commercial tests for state-level science assessment.[2] In the same survey, 14 states reported that they used a state-designed assessment test[3] and two states reported using both a commercial test and a state-specific test.[4] While some states are experimenting with alternative forms of assessment, it is safe to say that presently most state tests replicate the commercially prepared test format, with a less broad selection of questions (Davis & Armstrong, 1991). These norm-referenced tests are designed so that the achievement of a single student can be compared with another student, to a "typical" student or with other groups of students, or in order to make comparisons between groups of students.

The most common criticism of external assessment instruments is that, while they measure something with ease and precision, it is unclear exactly what they measure. In constructing commercial tests, state-level science curriculum guidelines are examined and individual items are developed to match frequently occurring topics. Because the discipline of science is so broad, providing a wide range of topics from which states design their curricula, it is not surprising that the selection of questions does not adequately match the curriculum guidelines of any state or district and may appear superficial and at times capricious for any given state. Further, there is serious question whether the efficient and well-established multiple-choice-question format is capable of capturing the skills and abilities that many experts agree are the essence of science. Most scientists agree that science is a difficult-to-describe interaction between the facts and concepts about natural phenomena and the processes and skills required to describe, explain and predict these phenomena. Often, because skills such as posing problems or generating additional data cannot easily be represented in the multiple-choice format, the test items seem to reduce science achievement to the recall of trivial facts.

Alternative Modes of Assessment

Alternative modes of assessment which are gaining prominence in classrooms are now being explored for state-level science assessment. At the national level during the spring of 1992, the New Standards Project (NSP) is pilot-testing new forms of student assessment in selected schools in 17 states. These new tests measure skills such as analysis, explanation, application and persuasion rather than recall. The usefulness and impact of this test is still unknown. In 1986 the Educational Testing Service (ETS) with a grant from the National Science Foundation (NSF), pilot-tested some items on the NAEP science assessment which were hands-on and required higher order thinking skills. The results indicate that though such items are expensive to design, administer, and score, none of these tasks of assessment development are impossible. States, especially California, Connecticut, Delaware, Kentucky and Maryland, are also beginning to include open-ended and/or performance-based questions on their state-developed tests. The performance-based tasks of the California Assessment Program (CAP), reported elsewhere in this issue, are receiving high praise for their ability to assess science thinking. The questions on state alternative assessment tools are grounded in verbs such as demonstrate, describe, evaluate, sort, test, predict, measure, compare, infer, etc. Almost all the external performance-based tests have a classification question.

Several factors affect the impact of these externally mandated tests. In states where an externally mandated test of student achievement is the sole source of data for accountability and subsequent distribution of funds, it is not surprising that local administrators admonish teachers to "teach to the test." Thus, it's reasonable to assume that whether science teachers teach so that their students will score well on an external test or model their classroom assessments on these external assessments, the assessments intended for accountability have an influence on instruction.

Before turning attention to classroom assessment, two national movements likely to influence student science assessment at the state and national level should be mentioned. In summer, 1992, the National Academy of Sciences (NAS) convened the first panels to discuss and design national standards for science teaching and learning. One of the these panels focused on issues related to science assessment, including student assessment, teacher assessment, and program assessment. While it is too early to predict the influence this panel may have on assessment for accountability and for instruction, it would be naive not to anticipate some impact. The National Research Council, the operating body of the National Academy of Sciences, was the sponsor of the development of the National Council of Teachers of Mathematics (NCTM) Standards Commission. The NCTM standards are becoming the benchmarks for examining mathematics teaching and learning.

The National Board for Professional Standards also convened its Science Standards Committee for the first time in spring, 1992. While the emphasis of the National Board is on setting standards for highly accomplished teachers, it is also difficult to imagine that this committee will not have an impact on student assessment, especially as the committee structures standards for teacher accomplishment that address how teachers assess student learning.

Classroom Assessment

Classroom science teachers have different purposes for and generally use different modes for assessing student science achievement. Diagnosing, monitoring and improving student learning and reporting this achievement to students and parents are the primary reasons why teachers assess student achievement. The great variety of classroom assessments, alternatively called internal assessments or assessment for instruction, focus on the individual student, are usually criterion-referenced, target a relatively small number of students, and are on-going. Teachers seldom rely on a single mode of assessment when concerned with student learning.

The most familiar of the classroom assessments currently used can be categorized loosely into two types: those that require extensive amounts of student time, energy and commitment to complete, and those that are less formal and more ad hoc. Some examples in the first group are tests, reports of laboratory, research or reading, and science fairs. In the second group are quizzes and teacher evaluation of student learning through small-group and class participation.

A range of test options are available to teachers. Teachers may use commercially prepared tests such as those described above, tests prepared by the textbook publisher as test-item banks, or their own teacher-written items that mimic these commercial tests. Although other forms of short answer items may be found (e.g., matching items, or sentence completion items), these tests are usually a collection of multiple-choice items. Multiple-choice items are favored because there exist mathematical formulas to determine difficulty and discrimination and the use of these formulas contribute to the reliability and validity of the items. While such tests generally are designed to have a single correct answer, it is not accurate to say that they are objective because the teacher's subjectivity influences which items from all those available are actually included on the test. In addition, the validity of such tests may be questionable if care is not devoted to the writing of each item. Extraneous clues to the correct answer, such as greater length, an unfamiliar word, more descriptive phrases, or inconsistency in grammar may invalidate the item. Frequently science teachers include opened-ended questions in which students are asked to analyze, synthesize, apply or evaluate science knowledge on tests.

Because science teachers believe research to be an essential aspect of doing and learning science, various forms of assessment focus on laboratory activity. In the course of more traditional item-response or essay tests, students may be asked to respond to items associated with science demonstrations displayed in the test room. Having students complete work sheets and/or write more formal laboratory reports about science experiences is a frequent mode of assessment used by science classroom teachers. Teachers also have students complete library research projects and reports of science events that are timely and/or newsworthy. The scoring of these assessments usually employs a combination of technical criteria developed by the teacher (grammar, number of items, strength and logic of the argument) and the teacher's professional judgement. Projects and science fairs also are used frequently for assessment by science teachers. These may range from projects that require students to pose and answer a problem to posters that display factual knowledge Again teachers or outside assessors rate the projects using some combination of inferences made from technical criteria and professional judgement.

Less formally, science teachers assess student learning by quizzes which may be versions of more formal tests that have fewer items and require less time. Teachers assess learning through making notes, preferably in writing, of the quality of students' contributions to class discussions. If small group work is an instructional strategy, students may engage in peer assessment.

Although it is frequently suggested that classroom tests should look more like those developed commercially and that state-level tests look more like what happens in a classroom, Shulman (1988) points out that all forms of assessment have strengths and weaknesses and that any group responsible for assessment needs to design a battery of assessments, knowing that each assessment in the battery is insufficient, to meet the specific purposes of the group requiring the assessment.

The New Movement in Assessment

In the last several years the "new" movement frequently termed alternative assessment, authentic assessment and/or performance-based assessment[5] has been growing in prominence among those concerned with assessment in science. Several factors have influenced this science assessment movement. Not the least of these factors is the development of performance assessments in other disciplines, especially the arts and literacy. The performance assessments in these areas provide models for designing and developing analogous science assessments. Research and development in these areas provide technical guidance to science assessors, as well as highlight the potential learning benefits that accrue from the use of such assessments. Another factor that has influenced the growing interest in performance assessments in science is the potential for such assessments to assist in addressing the long standing problem of how to assess the content aspects, the procedure aspects, and the interaction of content and process which is the essence of science. And there can be no doubt that concerns about student achievement in science have contributed to new definitions of science and explorations of new and better ways to teach and to learn science and to assess that learning.

In the enthusiasm for performance-based assessment in science, we must recall that such assessments are not new to science; however, the current emphasis on performance-based assessment allows science assessors to re-examine existing practices as well as to design new modes of assessment. Maintaining laboratory notebooks, writing laboratory reports in the style of professional journals, holding mock research conferences, and using lab practicals are familiar modes of assessment in science. The current emphasis on alternative modes of assessment assures those who use them that they are as valuable as tests currently in use.

Certainly Wiggins (1992,[6] 1989) is among the most thoughtful of the developers of authentic, performance-based assessments. From his experience and that of the Center for Learning, Assessment, and School Structure (CLASS) researchers, teachers and students, he has been offering questions, criteria, and guidelines for designing authentic assessments. Among the key points he has made are that authentic assessments:

- involve tasks which are worth mastering;
- simulate the challenges and constraints facing those who do science;
- are composed of "ill-structured" and non-routine challenges that require a repertoire of knowledge;
- contain contexts which are rich, realistic and enticing–with inevitable constraints of time and resources;
- focus on the ability to produce a quality product or performance, rather than a single right answer;
- typically include interactions between the assessor and the student;
- involve patterns of responses and behavior emphasizing habits of mind;
- have criteria that are known, understood, and negotiated as the performance proceeds;
- require scoring that focuses on the essence of the task and not what is easiest to score;
- produce results that can be reported and understood by all interested in such results–students, parents, teachers, local and state administrators, and the tax-paying public.

Without reference to science, Wiggins (1992) suggests some tasks that have been used by the Connecticut Department of Education in designing authentic assessment tasks in mathematics: given a graph, write the story that represents the data; or given student work that contains errors, find the errors and write a response to the student. Potential job roles also provide ideas for authentic assessments: as a museum curator design an exhibit and convince others the exhibit is important and interesting; as an engineer design a roller coaster or map the school property including light and/or heating specifications; or as an expert witness to Congress argue a point about environmental control or energy use.

While the definition and criteria for authentic assessment evolve in general, the new modes of assessment are having an influence in science. Three examples of alternative assessments currently being used for science assessment are concept maps, portfolios, and hands-on assessments.

Concept Maps. One of the alternative modes of assessment which is growing in popularity–one that need not be authentic or performance-based–is the use of concept maps for science assessment. Novak and Gowin (1984) describe concept maps as diagrammatic representations of meaningful relationships between concepts in the form of propositions. They suggest using concept maps for evaluation purposes, as well as during instruction. Generally those who have used concept maps experience their power as a strategy that requires students to express their knowledge in a clear, explicit, and meaningful manner. For example, Dana, Lorsbach, Hook, and Briscoe (1991); Roth (1992); and Tippins and Dana (1992)[7] report on using concept maps with middle and high school science students. All of these articles contain illustrations of student generated concept maps in science. For those unfamiliar with the procedure, a recent issue of the *Journal of Research in Science Teaching* (Novak & Wandersee, 1991) consists solely of articles on concept mapping and contains a bibliography of one hundred additional sources.

Portfolios. Portfolios for assessment are truly a hot topic. A portfolio is a collection of evidence that constitutes a compelling argument that a student is making progress toward a learning goal. That the evidence is all related to a goal is one of the characteristics that distinguishes a portfolio from a scrapbook or manila folder of unrelated material. Portfolios are an especially valuable mode of assessment for capturing context and change through time and for allowing individual students to show-off their personal strengths and talents.

Prior to 1988, research and development articles on the use of portfolios for assessment were relatively rare. However, a recent search of ERIC located over 180 articles, and this author has others on file that were not included in the ERIC database. Although most of these articles are on the use of portfolios in assessing writing and performing arts tasks, portfolios are gaining popularity in science assessment. Among the articles that might be of most interest to those concerned with science assessment are Collins (1992); Collins (1991); and Hamm and Adams (1991). Also, in the May, 1992, issue of *Educational Leadership* there are seven articles on portfolios. The one on using laser disc portfolios (Campell, 1992) and on mathematics (Knight, 1992) were especially intriguing to the author–one hints at the portfolios of the future while the other is from a teacher in a discipline closely related to science.

Portfolio assessment requires teachers and students working alone and together to examine serious questions about learning. Among the questions that need to be examined each time the portfolio process is used are:

- what are the goals for which evidence will be collected;
- who is determining the goals–teacher, student or both;
- what will count as evidence;
- which evidence will be required and which will be selected;
- how much evidence will be included in the portfolio;
- how will the portfolio be used;
- how often will the portfolio be reviewed;
- who will review the portfolio?

As there are no single correct answers to questions such as these, the answer that is negotiated gives each portfolio development process a local, contextual flavor.

Making decisions about the exact development of the portfolio in a local context does not imply that there are no guidelines for portfolios. The requirement that the evidence be related to a goal is paramount. Classes of evidence have been distinguished: 1) artifacts (materials usually produced in the classroom such as tests and lab reports); 2) reproductions (materials produced in the classroom but often not captured, such as raw data or first drafts of reports); 3) attestations (materials produced by others, such as thank you notes for out of class work or acknowledgements that parts of the work–figures, for example–where done by someone other than the author); and 4) productions (materials produced especially as evidence for the portfolio, such as a concluding, reflective statement). The use of the value-added principle has proven useful in determining how much evidence to include in the portfolio. That is, what value would be added to the portfolio if another piece of evidence were added. It is now clear that, analogous to science fairs and projects, there are two components to the portfolio scoring procedure: the technical criteria such as the presence of a caption on each piece of evidence and a more holistic, professional judgement about the power of the evidence in the portfolio.

Hands-on. Because of the fidelity to practice in science and the potential to capture both content knowledge and process skills, the form of alternative assessment that holds the greatest fascination for science assessment is hands-on assessment. Hands-on assessments are not new to science; as stated previously, science teachers have been conducting laboratory practical exams for years. The NAEP pilot-tested hands-on exercises in their 1986 national assessments. As earlier noted, California is among the leaders in designing and testing hands-on assessments at the state level. These attempts to use hands-on science tasks to assess large numbers of students and the renewed interest in the implications of hands-on science in individual classrooms have raised questions, however, not of how to do hands-on assessment, but of the value of doing so.

A team of researchers at the University of California at Santa Barbara (Shavelson & Baxter, 1992) have been designing hands-on assessments in science with the intention of conducting research. The hands-on investigations involved conducting an experiment to determine which of three paper towels soaks up the most water, inferring the circuitry of six "mystery boxes" and determining sow bugs' preference for various environments. Among the research questions they asked were: 1) could reliable measures of hands-on assessments be developed; 2) could the performance of students with different instructional experiences be distinguished; and 3) do performance assessments provide information about student achievement not available from multiple-choice tests. For each question they found a two-part answer–the good news/bad news scenario. Despite high inter-rater reliability in scoring, there was great variability in the same student's success on different exercises. Students who had been taught science as a hands-on learning experience were distinguishable from those who had not had such science experiences, but those assessments that required content knowledge were more sensitive to student differences than general process skills assessments. Lastly, though they claim that these assessments did not replicate the achievement data from standard multiple-choice tests (the correlations averaged .45), it was unclear what caused the differences. Among their conclusions is that "...unless carefully crafted and blended into instruction, assessments alone are not likely to boost achievement" (p. 25).

If it is true, as Shulman (1988) suggests, that all modes of assessment have strengths and weaknesses, there will be two tensions that surface as more and more new modes of assessment are designed. The first is related to purpose: what does this assessment add to the description of what a student has achieved in science. The second is relevant to issues of equity: how will this assessment both tap a common core of science knowledge that most agree represents what students should know and be able to do and support the diversity and individual differences among students. Those concerned with improving instruction will continue to applaud assessments that provide richer descriptions of student learning and better ways for students to display their accomplishments. Those concerned with accountability will applaud those that are efficient to design, administer and score and that produce reliable and valid data. Hopefully, as each group designs a battery of assessments for its own purposes, they will include some overlapping assessments so that students benefit most from experiencing assessment as a continuous, integral part of learning and not as an add on at the end.

Equity

It is not surprising that the advent of new modes of science assessment, both for accountability and for improving instruction, raises questions of equity. About ten years ago, there was a major concern about bias in large-scale tests. In attempt to control bias,[8] the *Code of Fair Testing Practices in Education* was prepared by the Joint Committee on Testing Practices of the American Educational Research Association (1985). At that time, the two major causes of bias were language (dialectical and phonological differences in the spoken language of a minority group and the mainstream group) and context (item examples and content unfamiliar to certain subgroups of the student population, such as minorities, the poor, and females) (Harmon, 1991).

While problems with test bias still exist, the advent of new modes of assessment introduce broader questions of equity. Webster's Dictionary (Guralnik, 1984) defines equity as fairness, impartiality, and justice. Can assessment be fair and just to all students? The need to address equity exists because of the student diversity in a science classroom. Students vary in their interests, skills, abilities, prior experiences, opportunities, values, habits, home and community expectations and more. Equity becomes a balancing act in which there is a common core for learning science that still allows for and promotes individual and cultural differences of each student. Equity is not achieved if diversity is destroyed.

Still, equity does not imply that there will be no differences in student science achievement. Rather, Malcom (1991) suggests assessments will be equitable if: 1) the rules of what is to be known and assessed are clear to all; 2) the resources to achieve are available to all; 3) the ways of demonstrating knowledge are many and varied; and 4) some of the things valued by differing groups are reflected in individual statements of what everyone should know and be able to do.

In the same article, as well as when she eloquently speaks, Malcom asserts that equity in assessment cannot be achieved unless a series of questions that cross all purposes for assessment and all modes of assessment are asked incessantly. Among the questions she proposes are:

- What is being tested? Specifically, what aspects within the discipline of science are being assessed? How well do these match the way the content was taught, the way they appear in practice and the knowledge and skill valued in the field?
- What specific goals for education are being tested? How are these goals related to the real-world use of the knowledge and skills being assessed?
- What exactly will be measured? To what extent will the measurement be direct or indirect, sequential or simulated? How differ-

ent, similar or independent is the information obtained in each type of measurement?

- Who will develop and score the assessment? What will be the relationship between the teacher, the assessment developer, and the scorer? How will these groups reflect on ethnic, gender, regional and other characteristics of students?
- To what uses will the assessments be put? Will there be a balance between instructional, monitoring, policy and accountability purposes? Who needs to know the outcomes and for what purposes?
- What will be the elements of assessment and of the specific examination units within the assessments? How will these elements themselves be evaluated for their ability to predict or indicate mastery of the desired characteristics for different segments of the student population?
- What will be the specific mechanisms of assessment? To what extent will the testing occur in the context in which the behavior will ultimately be judged? In familiar or unfamiliar settings? With or without technology? With familiar or unfamiliar testers? Individually or in groups?
- How will results be interpreted? What will be judged as an acceptable, unacceptable or exceptional response; what will be the response to outliers or to nonstandard answers? How will standards and ranges be set ? What will be the relationship of the standards to learners and to the judgement of content experts, especially where context dependent?
- How will the assessments be packaged? To what extent will an assessment be one subject at a time or across subject matter domains?
- How will we balance nationally agreed on and locally addressed curriculum standards with national and local needs for reporting student performance?
- How much difference from current modes of assessment and reporting will the public tolerate? How close to world-class standards do we dare assess? How much bad news can we tolerate?

This list is not exhaustive, yet it provides a good starting point for everyone concerned about learning, teaching, and assessment in science. Similar to the questions asked about portfolios, these questions do not have a single correct answer, nor can they ever be answered once and for all. But unless questions such as these are addressed regularly it is unlikely that the old or new modes of assessment for any purpose will promote science learning for all students.

Conclusion

One of the current phrases frequently used when discussing assessment is "high stakes." This term implies that the results of an assessment have a highly valued and/or long-term impact. The term also might imply that assessments that are responsible for promotion, admission to college, allocation of resources and such are more important than others and therefore need to be considered with greater care. However, any teacher or parent who has watched a child's eyes fill with tears over a score or observed an adolescent crumple a paper with disdain and despair knows there are no "low stakes" assessments. All assessments are important. Therefore, while some probe the individual aspects of different modes of assessment, others will deliberate the integration of assessment with instruction, curriculum and reform. There is too much at stake not to do so.

End Notes

1. This discussion considers only assessments that describe student learning at the national, state and classroom level. Other assessments such as the Stanford-Binet Intelligence Test, Advanced Placement Test or Scholastic Aptitude Test, generally used for student placement are not considered.
2. Alabama, Arkansas, Delaware, Georgia, Idaho, Louisiana, Mississippi, Missouri, New Hampshire, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Virginia, West Virginia.
3. California, Conneticut, Florida, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, Missouri, New Mexico, New York, North Carolina, South Carolina.
4. Missouri, South Carolina.
5. While frequently used interchangeably, there are differences among the three. Alternative assessment

seems to mean any assessment task that is not a traditional paper and pencil objective or essay question; performance-based assessment implies that the student must do something besides write a correct answer to a question; authentic assessment implies a high degree of fidelity between the assessment task and the practice of the discipline.

6. The May, 1992, issue of *Educational Leadership* was devoted to performance assessment.

7. The March, 1992, issue of *Science Scope* was devoted to assessment in middle school science.

8. Bias may be defined as a quality of a test that causes it to measure different populations differentially.

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New Directions in Science Assessment in California: Moving "Beyond the Bubble"

Kathleen B. Comfort

Moving "Beyond the Bubble" has become the major theme underlying the development of new science assessments in many states. In the past, large-scale assessment in most states has taken the form of standardized multiple-choice tests that ask students to "bubble in" the correct answer. Current research suggests that changing the way we measure student achievement may improve the quality of science instruction. In California, recent legislation has focused attention on the need for improvements in how we measure student learning, what we measure, and how we use information from measures to restructure educational programs. In science, a variety of innovative performance measures are being developed, field tested, or implemented: performance tasks, open-ended or free response questions, modules, and portfolios. This paper discusses the experiences of the California Assessment Program with these new measures.

Moving "Beyond the Bubble" has become the major theme underlying the development of new statewide assessments in many states including California. Instead of discriminating between bubbles on a multiple-choice test, students are required to demonstrate understandings of concepts and processes, to solve problems, and to engage in hands-on performance tasks. If the goal of instruction is to teach students the expressive side of communication and problem solving, tests must be patterned after instruction; they must emphasize production, creation, and performance–doing rather than discriminating (Carlson, 1989). Assessment tasks themselves must be intentionally complex, moving away from the clean, unidimensional, factorial purity of the past. Only tasks that call for integrating and applying learning can reinforce sophisticated goals of instruction. The tasks should be multi-dimensional in skills assessed, multi-sensory in stimuli presented, and multi-modal in response formats (Carlson, 1989).

It is anticipated that these new forms of assessment will reinforce good curriculum practices, encourage thematic teaching, and emphasize learning through hands-on experiences. Most important, they will go beyond the levels of recall and paraphrased recall to include activities in which students use the concepts learned and relate them to other concepts (Comfort, 1991).

In the past, in most states, large-scale assessment has taken the form of standardized multiple-choice tests that ask students to choose the correct response from a set of alternatives and to "bubble in" their choice (R. Anderson, 1990). These standardized tests have become the main criteria that many schools use for making decisions that affect instruction and the quality of teaching. Unfortunately, these tests have many negative consequences: they tend to narrow the curriculum; encourage the teaching of disconnected, low level facts; frustrate teachers and students; confuse the public's understanding of the schools; and undermine school improvement efforts (Comfort, 1991).

Research shows that students learn what they are taught and that teachers teach what they are held accountable for. The conclusion that achievement testing profoundly affects the quality of U.S. education is inevitable (Shavelson, Carey, & Webb,

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1990; Resnick & Resnick, 1991; Walker & Schaffarzick, 1974). It is not surprising, then, that both the general public and the professional community are dissatisfied with the incessant use of paper-and-pencil, multiple-choice tests, not only to assess student knowledge and understanding of subject matter but to establish accountability (Frederiksen & Collins, 1989; Shavelson et al., 1990). Current research also suggests that to achieve educational reform, assessment must be realigned to match reform. With such realignment, when educators "teach to the test," they will be teaching the 'big ideas' advocated by reformers, and the quality of science instruction will be improved (Wiggins, 1989; Raizen, 1989; C. Anderson, 1990, November; Heins, 1989).

CAP Progress

The California Assessment Program (CAP) has begun introducing performance-based assessments that indicate more directly what students actually know, how well they can think, and what they can do. In 1987, CAP introduced its first performance-based test, the grade 8 writing assessment in which students composed an essay in response to a prescribed topic. This assessment was extended to grade 12 in 1988. Another change at grade 12 occurred in 1990 when open-ended mathematics items, for which students must construct their own solutions, were administered, scored, and reported (R. Anderson, 1991).

CAP has also initiated pilot portfolio projects in English/language arts, mathematics, and science in which students and teachers collect and evaluate an array of student work throughout the school year. Language arts examinations integrating reading and writing were field tested for the first time in spring, 1990. Students were asked to read and write a number of short responses, participate in group discussion, and compose an essay to provide evidence of comprehension (R. Anderson, 1991).

In history/social-science CAP is developing assessments which will allow students to demonstrate breadth of learning as well as ability to clarify issues, recognize relationships, determine causes and effects, interpret evidence, and present an argument. Assessment modes under development include written tests, portfolios of student work, and integrated performance tasks (R. Anderson, 1991).

Science Assessment: Spring 1990 and 1991

In science, the new assessments will be aligned to the 'big ideas' recommended in the *California Science Framework*. These 'big ideas' (e.g., "living things evolve through geologic time") used to frame an entire K-12 science curriculum including life, earth, and physical sciences, as well as technology and environmental education, are connected, integrated, and interwoven by themes of science (energy, scale and structure, patterns of change, stability, systems and interactions, and evolution). Scientific processes (observing, communicating, comparing, ordering and categorizing, relating, inferring, and applying), attitudes, and manipulative skills that contribute to the 'thinking curriculum' are also incorporated into these new performance assessments (Comfort, 1991).

The CAP tests are developed by science educators, including grade level teachers, science supervisors, university representatives, and scientists on the CAP Science Assessment Advisory Committee. The California science networks, including the California Science Project (CSP), the California Science Implementation Network (CSIN), and the California Secondary Scope Sequence and Coordination Project (SS&C), work with CAP to design, pilot, and field test the new tests, as well as to provide professional development opportunities for teachers.

In the spring of 1990, CAP, in conjunction with the California Science Project (CSP), and the California Science Implementation Network (CSIN), conducted the first statewide field test of performance assessment in science at grade 6. Approximately 1000 schools participated.

The testing format consisted of five stations with one task per station. Each task took approximately 10 minutes, and the students rotated through the stations, completing all five performance tasks in one class period. Five tasks challenged students to integrate manipulative and thinking skills with their knowledge of the content of science. Students engaged in hands-on activities and recorded their observations and conclusions on student response forms. As one example, students had to build a circuit with materials provided, predict and test the conductivity of various materials, test their conductivity, and record the results. Other tasks required students to observe, classify, sort, infer, detect patterns, formulate hypotheses and interpret results. In each task, students had to move beyond the activity and develop a conceptual understanding of natural phenomena. A research pilot was also conducted during the field test in which a sample of schools administered two versions of the test: one administration utilizing the regular station approach, and a second administration in which teachers utilized one of 6 variants. The variants included time, delivery of instructions, and format (cooperative groups and diads) (Comfort, 1991).

In spring, 1991, CAP, CSP, CSIN, and the SS&C Project conducted a second field test of performance-based assessment at grades 5, 8, and 11 in over 2000 schools. Students at grade 5 worked with a partner to complete three performance tasks. The three tasks were designed to assess a student's ability to: analyze non-living substances and determine their suitability for living things ("Spaceship U.S.A."); sort, classify, and rationalize their system of classification using a variety of fossils ("Fossils"); and determine the effect of wind direction on the motion of pinwheels, compare the amount of work done by pinwheels of different sizes, and relate this learning to other situations ("Wind Energy").

Students at grade 8 also worked with a partner to complete three performance tasks. The three tasks were designed to assess a student's ability to: analyze common attributes of fossils and establish relational patterns ("Fossils"); perform a chromatography experiment and apply information obtained to real life investigations ("The Mystery Note"); and manipulate variables and determine the relationship between distance, force, and work ("Happy Trails"). The "Fossil" task at grade 5 spiraled through grade 8, building in complexity. Fifth graders were asked to sort a variety of fossils found in a dig into groups that appeared to be related. They were asked to develop their own classification system and defend it by adding another fossil to one of the groups. By the eighth grade, students were asked to observe a group of fossils and develop a rationale for their development and differences over time. The grade 8 "Happy Trails" task integrated science and mathematics (Comfort, 1991).

Working in triads, students at grade 11 were presented with an array of evidence that required them to coordinate their science abilities from biology (use a microscope to investigate properties of different hair samples), with chemistry (conduct a chromatography test to determine who wrote a note found on the body), and earth science (conduct profiles and pH tests on samples of soil found on the victim's shoe), to investigate the death of Mr. James Obechki to see if a crime had been committed. The objective of this coordinated investigation was to assess students' ability to use scientific processes and tools to communicate thinking processes and to demonstrate understanding of concepts that are connected and integrated among the sciences.

Spring 1992

In spring, 1992, CAP, in conjunction with CSIN, CSP, and SS&C, conducted a third field test of performance based science in 3500 schools at grades 5, 8, and 10. The performance tasks, extending over three days, one class period per day, consisted of one in-depth, coordinated (life, earth and physical science) task per grade level. Part I, administered on day 1, consisted of pretest activities and questions to be completed by individual students in order to determine what prior knowledge students might bring to the task. In Part II students worked with a partner to complete a series of investigations, collect data, and discuss their findings. Students worked individually on Part III in order to analyze their data and record their conclusions. Part III also contained a post test or reflection activity and questions to determine if the task provided an opportunity to learn about the "big ideas" being assessed. Analytical and holistic scoring rubrics were developed in conjunction with researchers from the University of California, Santa Barbara, and several thousand student papers were scored.

To date, several different test designs and formats of performance tasks have been utilized by CAP. Since performance assessments in science are new, and the "perfect task" has not yet been developed, the CAP Science Assessment Advisory Committee felt it expedient to experiment with a variety of different designs before forming a recommendation for statewide assessment. CAP is currently participating in a National Science Foundation sponsored project with RAND, the University of California, Santa Barbara, Stanford University, and the Far West Laboratory to study the psychometric qualities of performance assessments in science. Also, data collected from the 1992 summer scoring sessions, along with data from both the 1990 and 1991 tests, will be analyzed to determine the best qualities of the performance measures.

Scoring of Student Papers

On a multiple-choice test, students take a lucky guess and "bubble" in a preselected response on a computer-readable test booklet. This booklet is then scanned for correct answers and a scale score is usually assigned. In performance assessments, such as the ones just described here, students are encouraged to demonstrate understanding by conducting an investigation, collecting and analyzing data, and forming a conclusion. These types of assessments have no prescribed answer, but allow for a variety of appropriate student responses, including writing, drawing, and/or the manipulation of data. In order to accommodate a wide range of responses, as well as to encourage the evaluation of the student's entire thinking process, holistic scoring guides or rubrics were developed for all tasks (in 1990 and 1991) instead of marking specific points according to a scheme as is done on an analytical scoring rubric.

Specific rubrics developed for each task consisted of a six point scale. At the high end of the scale–six–a student demonstrates an in-depth understanding of the concept and an ability to communicate it effectively; at the low end the student shows little evidence of understanding and little ability to communicate ideas.

At regional meetings held throughout the state, teachers scored student papers using the holistic rubrics. Many teachers shared student papers and results with CAP for additional analyses. Although student scores will not be reported, a report-of-findings on student results from both the 1990 and 1991 field test data is being developed by the CAP Science Assessment Advisory Committee.

Analytical scoring rubrics were developed under the direction of researchers from the University of California, Santa Barbara (UCSB) for the 1992 tasks. The scale of the analytical rubrics ranged from 3 to 18 points and contained exemplars of student responses. In comparison to the holistic rubrics, many teachers felt that the analytical rubrics took longer to use and were not as conceptually oriented as the holistic rubrics. Data from the 1992 field test are currently being analyzed and studies are being conducted by psychometricians.

In July, 1992, CAP worked in conjunction with the regional consortiums and the subject matter projects to provide teachers in all content areas with the opportunity to become involved in the scoring of performance-based tests. The Region 8 Professional Development Consortium cooperated with the Los Angeles, Santa Barbara, Ventura, San Luis Obispo, and Kern County Offices of Education, along with the University of California, Santa Barbara, the South Coast Science Project and the UCLA Science Project to host two week long scoring and professional development sessions for teachers in that area. Sixty teachers participated at either the UCSB session or the Long Beach session.

Many teachers stated that the CAP summer scoring sessions provided the opportunity to reflect on science education, assessment, and program development. They also felt that by scoring student papers from all over the state they gained valuable insight into student understanding of important scientific concepts. It is anticipated that these teachers will serve as lead teachers in future CAP scoring and professional development activities.

Performance Standards

Performance standards are bench-mark descriptions of the quality of performance against which actual student work can be compared. The performance standards provide a basis for trained teachers to make judgements about the level of accomplishment demonstrated by student work (Pandey, 1992). The California Assessment Program (CAP) is currently mandated to develop common statewide standards in all content areas, including science. All new tests will be built upon these standards and they will be used to report school level results.

In science, performance standards will be based upon a goal for all students to achieve scientific literacy. The CAP Science Assessment Advisory

Committee "working definition" of scientific literacy includes six levels with Level 6 indicating the highest quality of performance and Level 1 the lowest. The following "draft" dimensions are embedded in the six levels:

- conceptual understanding–understands and communicates the main concepts of science and the connections among them;
- performance–uses scientific processes, concepts, and tools to solve problems and to increase/demonstrate conceptual understanding;
- application–uses conceptual understanding and performance to solve new problems which reflect scientific attitudes, values and social responsibility.

A variety of measures (tasks, open-ended questions, portfolios, and thematic/conceptual multiple-choice) can be used to assess the dimensions of scientific literacy. These measures will reflect the "big ideas" of science recommended in the science framework and it is these performance standards which will guide the development of the measures and the scoring rubrics. A more complete discussion of these instruments appears in Collins' article in this *Review.*

Impacts of the Performance Assessment

Overall, the performance components of the CAP science field tests were enthusiastically received by teachers and students alike. Nearly all teachers reported that performance tasks provided students with a meaningful and exciting learning experience, in addition to yielding valuable information unobtainable through traditional testing methods (Comfort, 1991). Teachers also indicated that the tasks were well-conceived and challenged students to work through the questions posed by each task, using higher-order thinking to arrive at possible solutions. (See also Hackett & Floore in this *Review.*)

Many teachers reported that students who participated in the field tests of performance based assessment exhibited high levels of curiosity and motivation and enjoyed tackling the questions posed by the various investigations. Many students wanted to repeat the tasks and explore the implications of their results in greater depth. Teachers also reported that many students did not exhibit the tension typically associated with more formal types of testing. Although a few students were hesitant at first, teachers observed that nearly all of those students lost their initial apprehension as they became involved in the tasks. Student evaluations of the performance testing included the following:

> The hands-on-test was fun and terrific. It is a lot better than the ordinary test. It is easy to understand, and you do not have to memorize anything. The hands-on-tests I did made me realize how much I really do know about science. I wish every test could be like this.

> The first test on electricity was neat. I had a little trouble building the electrical circuit and kept thinking over and over, Benjamin Franklin was a genius. I couldn't believe I actually made an electric circuit that worked.

> I thought this kind of test is less stressful than a regular fill-in-the-bubble test. I would rather take hands-on tests then fill-in-the-bubble tests. You still must study, but not remember every answer. This way you do things by brain, not by memorization.

> This test was very unique. I liked the way I worked under pressure to solve a case. Labs like this make science interesting, learnful, and enjoyed.

> I was able to escape boring chemistry and try it (science) in the real world.

Many teachers stated that performance based assessment would encourage schools to implement the recommendations of the 1990 *California Science Framework for Public Schools, Grades K-12.* Many stated that its incorporation into the state testing program would discourage the use of standardized, multiple-choice testing and dittoed worksheets as primary assessment and teaching tools in the classroom. Advocates of hands-on teaching and testing felt that this assessment provided them with the validation needed to implement innovative teaching and testing techniques at the local level. When asked if this type of test fits in with the current reform efforts in science, one teacher reported:

I feel a part of the national effort to reform science education and restructure assessment. The CAP field test in science has already been very instrumental in bringing about change in our district. We also feel that it is helping to raise the standards for our students and create a higher interest in science. The benefits to kids is relevant and exciting. California's science networks (CSIN, CSP, and SS&C) are a model of cooperation and inspiration. I am immensely honored to be a part of them.

Professional Development for Teachers

All teachers administering tests in 1990, 1991, and 1992 received two days of training: one day in test set up and administration, and a second day in scoring and analyzing results. Teacher trainings were conducted at 22 county offices of education. Teachers participating in CSIN, CSP, and SS&C provided leadership, support, and assistance to grade level teachers in their regions of the state by serving as trainers and facilitators for these sessions. Debriefing sessions were also conducted and many teachers had the opportunity to review and make recommendations about the design of the test, administration of tasks, and the impact of performance assessment on curriculum and instruction. All teachers were requested to evaluate the test and their training. Teacher evaluations included the following comments:

> This one test has done more in our district to support meaningful science instruction improvement than any other single event. The nature of this testing gets to the heart of needed reform in science instruction. It authentically measures our students' ability to observe, test and draw conclusions.

> I appreciated having input into assessment rather than having it imposed 'from above.' Students and the science program will benefit because the test has been created and revised by real teachers in real classroom situations.

> The neatest part was watching my kids taking the test. I learned so much about them, especially the poorer student. Some of them did quite well on this type of assessment.

> One of the strongest impressions of the power behind performance assessment came a few days after our students took the test. One female student that appeared not to be the "school girl" type asked in her science class when they were going to take the test again...it was fun! The response from her teacher was of surprise. It was the first time she had shown any interest in anything about science.

Many teachers reported that the CAP training provided the opportunity to not only gain experience with performance assessment and to get in on the ground floor of a major national movement in education, but also to share ideas and network with other teachers.

Other Components of CAP Science Assessment

The performance task is one component of the CAP science test. Students at all grade levels also complete a small number of thematic/conceptual/integrated multiple-choice items and open-ended questions. The multiple-choice questions contain a cluster of six coordinated and/or integrated (life, earth, and physical science) items that are woven together by a short storyline. Instead of focusing on the recall of specific information, these new items require students to think through the big ideas of science recommended for a particular grade level. Students also have the opportunity to justify or briefly write why they chose a particular answer.

Open-ended questions are non multiple-choice questions that allow students to think, solve problems, and communicate possible solutions. Students are presented with a problem and are encouraged to construct their own answer by writing a short paragraph, drawing a picture, or manipulating data on a chart or a graph. By means of open-ended questions which allow for a range of many possible responses, teachers effectively access student thinking and understanding. The questions are scored using holistic scoring rubrics similar to the ones used for performance tasks.

In addition to the field testing of performance tasks, open-ended questions, and multiple-choice items, CAP launched a Phase I Science Portfolio pilot in 200 schools in the fall of 1991. Using a constructivist approach, teachers from around the state had the opportunity to meet in regional sessions to develop the guidelines for science portfolios for grades 5, 8, and 10. These same teachers reconvened throughout the year to refine and revise guidelines and criteria, and to share experiences regarding the use of portfolios in the classroom for science.

According to teachers from around the state, science portfolios (collections of student work), often show the development of works in progress. They allow teachers to judge student growth over time. Students assist the teacher in selecting "best works" to be included in the portfolio. Many teachers agree: portfolios serve as an important tool for increasing student self-esteem. The portfolio is a multi-modal assessment and record of student growth and progress. It provides students with an opportunity to make connections and to explain their understanding of science to someone else. The teacher can use a portfolio to evaluate the progress of the class, the student, and the curriculum. A portfolio can be valuable to the student because they evaluate their own work, gain a sense of pride, and express a purpose. As in real life, portfolios give students the opportunity to put their best foot forward, to grow, and to change and evolve.

As a result of the Phase I pilot, a draft document, *A Teacher's Guide to Portfolio Assessment in Science*, was developed and disseminated. In addition to the draft guidelines, a science portfolio newsletter, *The Watershed*, was also developed and is being disseminated. The goals of the newsletter are to: provide a forum for the discussion of portfolio assessment that supports the direction of the California Science Framework and the new directions of CAP; suggest resources and helpful hints for teachers in the use of science portfolios; provide references of current research; and showcase examples of student entries.

The Phase II pilot for 1992-93 was extended to four regions of the state, and in addition to the continuation of piloting and refining the draft guidelines, participating teachers were requested to pilot a variety of research designs such as: cross curricular portfolios at the elementary level; coordinated science portfolios at the middle school and junior high level; standardization of portfolio entries; and the judging/evaluating of student portfolios. To date, over 300 teachers have committed to: attending all three meeting in their regions; assisting with the revision and piloting of the guidelines; piloting portfolios in their classes and sharing portfolios with CAP; piloting research designs; standardizing student entries per region; and assisting other teachers in the use of science portfolios.

The Future of CAP Science Assessments

CAP will continue to modify and field test the new assessments based on the results of the initial trials. It is anticipated that CAP will conduct both a prototype administration and a field test in spring, 1993, in a small number of schools. The design of both the prototype and field test will contain three components: multiple-choice with some justification; open-ended questions; and performance tasks. Schools participating in the prototype administration will have the option of reporting their science scores at the school level with mathematics and English/language arts; CAP will purchase kits of materials for the hands-on component and will score student papers. Schools volunteering to participate in the field test will purchase kits of materials for the hands-on component and will score their own student papers. CAP will continue to work with CSP, CSIN, and SS&C to provide teachers with professional development opportunities in the set up, administration, and scoring of the new assessments.

In order to prepare for the implementation of these science assessments in spring, 1994, CAP is currently designing a rationale and content document that will inform the field of what will be assessed. The purposes of a Rationale and Content for Science are to: define the big ideas of science, as recommended by the 1990 California Science Framework; identify which big ideas would be assessed by CAP for grades 5, 8, and 10; provide examples of the different forms of assessment; and provide the standards by which student achievement would be judged.

The New Integrated Student Assessment System for California Schools

Due to new legislation in the fall of 1991, CAP is currently undergoing a restructuring process entailing a shift toward the reporting of individual scores. Along with a reduction in the reliance on multiple-choice testing, a need for a statewide student assessment system was also recognized: a system that would provide information about the progress of individual students to all teachers and students, as well as a set of performance standards on which to base these tests and reports of results. Governor Wilson signed SB 662 into law on October 9, 1991, ensuring a new vision of assessment for California. This vision sees the assessment process as having a direct impact on individual students and their parents–key stakeholders who, until now, had been largely excluded from assessment. It will ensure that students leave school prepared, in the words of Dennie Palmer Wolf, "... to ask questions, solve problems and have high standards for their work and the quality of their lives." In essence, and quite simply, the primary purpose of the new assessment will be to improve instruction for all students (Carlson, 1992).

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What You Test Is What You Get

Erla Hackett
Susan Floore

How would you like to walk into an urban 8th grade classroom of 34 students in which 100%–ALL!–of the students are on task, conversing quietly in teams of two, using equipment purposefully, and even recording data? Students new to English are feeling comfortable using their native languages. Normally disruptive students are focused. Cooperation is in evidence everywhere. Believe it or not, this... (shudder)... is a test.

No, there's nothing nefarious going on. These San Francisco students are field testing the new Performance-Based Science Assessment component of the California Assessment Program. Feel the winds of change.

The diverse demographics of San Francisco schools present problems that will be faced by many school districts throughout the country in the near future.

A few San Francisco public school realities:

- minority populations (becoming the majority in schools) require sensitivity and validation for who they are within their family, ethnic community and the larger San Francisco community;
- more than 50% of public school students are proficient in languages other than standard English–an additional third are limited or non-English speakers (SFUSD, 1992);
- class size has increased to unprecedented loads with consequent instructional implications;
- special needs students, including those identified as learning disabled, students with physical disabilities, emotional problems, attention deficit disorders (not yet identified and included in the "official" special education programs), early bloomers, and others, are mainstreamed into science classes with no additional instructional support;
- students with wide ranges of traditional academic abilities as well as developmental stages appear in every classroom;
- resources for equipment and supplies are shrinking;
- family structures have changed, with many students having more than one home and assuming traditionally adult roles and responsibilities;
- societal expectations of schools as care-givers for youngsters are increasing;
- work and family demands on parents preclude their involvement with their children's education;
- parental knowledge is lacking about how to best assist their children with their studies;
- problems of transient student populations between schools and a 16.4% cumulative dropout rate continue (SFUSD, 1990); and
- evidence indicates the compromised physical health of adolescents (CDE, 1987).

The science curriculum must address the di-

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verse needs of these students in order to prepare them for a changing and demanding work place where workers must be flexible and work "smarter" using problem solving techniques and cooperative strategies. Tomorrow's successful workers must view learning as a positive, life-long activity. We believe that performance testing best meets the needs of today's "at risk" populations and tomorrow's work force. While traditional standardized testing validates reading, word recognition and recall, performance testing will add the important facets for the assessment of conceptual understanding and social growth.

Not yet in step with the needs of today's students, assessment must evolve to measure what students need to know. As classroom teachers, we have observed discrepancies between students' conceptual understandings and their performance on traditional language-based standardized tests. We are convinced that often many students know more than these tests indicate. Student interviews which allow for delving into areas of conceptual understanding have demonstrated that some students know much more than that reflected in test results while others with good word recall and reading skills may not have mastered the concepts. Listening to student groups share and negotiate ideas during laboratory activities reveals not only their understandings, but also their development of needed social skills. Some students can communicate conceptual understandings through diagrams and illustrations independent of language.

Assessment does not yet reward whole realms of performance considered necessary for today's graduates to be successful and responsible members of their communities. Some of these neglected performance areas include positive social interaction, cooperation and conflict resolution, decision making, problem solving, creative thinking, and consensus building. Inasmuch as all these have a place in good curriculum and instructional strategies, they should have a place in evaluation, too.

Traditional tests do not often measure students' real achievements and, in fact, deny many major accomplishments. Thought processes are often sacrificed to recall and concepts to word recognition. Auditory and kinesthetic learners are usually at a disadvantage. Still other students are focused socially, learning needed social processes and skills. They are taking major steps toward maturation. For these students, social contacts are paramount and they put these interactions ahead of any academic concepts. Accomplishments of these students, while real, are often not recognized by the present system. For them, performance testing in pairs integrates social interaction with the mastery of academic concepts.

A further complication is the political reality that schools are rated by these scores. This evaluation drives instruction to some extent, to the detriment of richer, more complex experiences. If the accomplishments of all students are to be evaluated accurately, accounting for factors that put some youngsters "at risk", assessment must reflect what really should be measured. The need is clear and increasingly urgent for more equitable assessments that are not solely language based and that measure intelligences other than verbal ones. The more a curriculum is influenced by current standardized tests, the less it prepares students for the changing demands of the work place with its new and greater technologies and expectations.

We feel that the Performance Assessment in the science portion of the CAP is one attempt to validate our students and their multiple intelligences. It also meets the changing demands of an evolving society and gives useful information to educators and decision makers.

In our field test of more than 120 students, the CAP posed three life-like problems for solutions. At one station, students solved a mystery using chromatography. At another station, students studied different fossil forms in different layers and made inferences and predictions. In a third, they examined the merits of two bike paths on different terrains, made choices and justified them. Students worked cooperatively in pairs, manipulated equipment, and recorded their data by answering questions on individual test forms. Some open-ended questions provided flexibility to accommodate differing logical interpretations. Tested tasks were timed.

Holistic scoring allowed credit for thinking processes, even if the task was not completed. The papers were scored by the students' teachers according to a rubric developed by the State Department of Education. The last page of the test booklet was a survey of student opinion about the test itself.

Student opinion was generally positive and even enthusiastic about the test experience. Representative student comments included:

"Can we do this again tomorrow?"

"I've never taken a test like this. It was fun!"

"I love working with a partner."

"It's more comfortable with someone to talk to."

"I learned something from this test."

"Before we had to do a lot of reading and this one has things that we can actually do."

"I liked the test the way it is, thank you!"

"I don't like any test, but this was better than most."

Other comments indicated specific parts of the test that were unclear, some were non-committal, and very few comments were negative. From the teachers' perspective there are major problems to be worked out and warnings to be given. We encountered problems in time, space, equipment and logistics. Some were anticipated and covered during a release day for training in test administration and others were discussed during a test evaluation and training in holistic scoring on a release day after the test was given. (see Table 1)

With all of these problems, would we do this again? You bet! Students enjoyed the test itself; in fact, many asked if they could do this type of test again. This test reflected thinking skills (street smarts) so that non-motivated students had success. Students who were not fluent in English and those who use alternative dialects were not so impeded by the test format. Students were deeply involved in problem solving, demonstrating that the tasks had relevance for them. They used their social skills of cooperation, give and take discussion, negotiation, and independent thinking as some agreed to disagree. Both oral and written language were used effectively.

As teachers, we felt that we were seeing a more accurate reflection of how students process information. The concreteness of tasks revealed transitional and abstract thinkers. This would be valuable information for inclusion in a portfolio or an individualized education plan. Multiple intelligences were in evidence as we watched them doing and discussing.

Table 1

Addressing Test Administration Challenges

Problem	*Solution*
preparing stations from the kit provided	four high school students and two teachers (us) volunteering one full work day organizing and preparing stations for two schools (tips and materials such as labels provided from the training were invaluable)
building of partitions	student volunteer time
not all needed materials provided	laminating, extra chromatography paper, folders for partitions etc. provided by us and the site
participating 8th graders were expected to be tested the same day	because of shared space and equipment, each teacher tested on a separate day
no time for directions – test took the full period without student opinion survey	built a practice test with three short activity stations so students knew their partners, stations, and how to move
familiarity with specific equipment lacking	spring scale included in practice test
no time for opinion survey	devoted third day to CAP
time for scoring	part done on release day-volunteer time needed for completion
logistics for moving students through test stations	physical rearrangement of room required that other grade level classes be taught elsewhere
test given in early April	hope that end of year topics are not included in test
cost for test	covered by S.F.U.S.D., including site materials used
administrative support essential	administrative support present

Despite the benefits of performance testing, implementation will be difficult. Funds will be needed for test materials and release time for teachers to be trained in test administration and holistic scoring. Teachers must to be committed to the extra effort and time needed. To be meaningful, results must reflect site considerations.

As classroom teachers, we can see how standardized testing impacts the curriculum we work so hard to develop and make relevant, meaningful, and useful. Should performance testing become wide-spread, more teachers would be encouraged to engage their classes in activities. A shift from a content based curriculum to one that includes development of social skills as a major focus will help students become more positive, effective members of their school and community.

If performance testing is integrated with the curriculum, effects could be even more widespread. More students would be truly learning, more successful, and involved. More positive student attitudes would help to reduce behavior problems. Funding patterns would need to shift to emphasize materials. Textbooks would assume a less central role, as advocated by the new Science Framework for California Public Schools (CDE, 1990). Pre- and inservice teacher training would need to change to support these changes. In addition to teacher training, public education would be needed so that parents and the community at large become familiar with the value of learning how to learn and how to cooperate and collaborate on projects.

While a collection of facts has value, it must assume its proper perspective in our students' overall education. The number of science "facts" is exploding geometrically and no one can keep pace. "As we shift from an industrial society to an information society, traditional notions of basic scientific, mathematical and technological competencies are being replaced by ever-higher expectations of our citizens. The production, access and utilization of information have become keys to personal, social, and global well-being" (SFP 2061, 1991). Major changes will be needed, but major changes are happening now and performance testing is one of the marching bands. We are very glad to have been marching in this performance field test in spite of the time and effort it took. It's an exciting time to be an educator!

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Roles for Technology in Science Education Research

Patricia K. Freitag

"...technology extends our abilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach further with our hands, voices, and senses." (F. James Rutherford and Andrew Ahlgren, *Science for All Americans*, p.23)

Computers have become increasingly critical to research production, collaboration, and dissemination. Although educators have been among the last to join the technical revolution, current innovations and interactive technologies open possibilities for new teaching and learning experiences in the classroom and new lenses for observing and recording classroom interactions and behavior. Specifically, interactive technologies and object oriented courseware can be used to encourage students to become active contributors of knowledge in the classroom. These technologies may also be used to record data about students' learning processes. As these technologies become increasingly available in schools, the science education community should be evaluating the potential quantity and quality of data available for all aspects of science education research.

Introduction

One challenge of reviewing and proposing roles for technology in science education research is that the literature is widely dispersed. Two major types of science education research incorporate teaching and learning technologies: 1) studies of the effects of using technology for teaching and learning and 2) studies that use technologies in innovative ways for research. These two categories are by no means mutually exclusive. Articles may be found in journals of science education research, general research methods, instructional innovations, cognitive science, software and hardware technical or review journals, and journals focussed on technical or innovative uses of teaching and learning technologies. Here, the roles and potential roles for technology in science education research are described through an adaptation of Sherwood's (1984) framework of types of computer use in educational settings–learning *about* computers, learning *from* computers, learning *with* computers, learning *about thinking* with computers, and *managing* learning with computers.

Education research should strongly influence how available technologies are used for teaching and learning. Instead of publishers substituting multimedia resource packages for textbooks allowing the teacher-centered, text directed model of teacher as information deliverer or mediator to be maintained, researchers should point the way toward the use of teaching and learning technologies to transform classroom practice consistent with their findings.

Informing and participating in the development of new teaching and learning resources have always been important avenues for scientists and education researchers to contribute to K-12 science education. Modeling innovative ways of teaching and learning with and from technologies will be an important aspect of preparing science teachers for multimedia learning environments (Linn, 1987).

Research About Technologies

Along with the increasing availability of technical resources for classroom use (Becker, 1991),

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there has been a corresponding explosion in the number of research studies focussed on the impact, effects, and outcomes of computer assisted instruction (CAI) (Collins & Morrison, 1992; Martin & Szabo, 1990), computer-based learning (CBL) (Larkin & Chabay, 1989), microcomputer based laboratory (MBL) (Linn, Lewis, & Songer, 1992; Friedler, Nachimias, & Linn, 1990), and most recently multimedia environments (Leonard, 1989; Lanza & Roselli, 1991; Billings & Cobb, 1992; Leonard, 1992). Myriad studies compare CAI to more traditional methods of instruction and model teaching strategies with computers (Johnson, Johnson, & Stanne, 1986) and interactive technologies. In addition, some studies compare hardware systems, software programs, and new curriculum materials as they influence student achievement, learning, perception, equity issues, and motivation (Krendl & Lieberman, 1988). The role of computers and interactive technologies as the subject of research has been important in breaking down the fear of computers in schools, providing models for the effective use of the technology in the classroom, raising curriculum issues about computer literacy, content, and understanding, and informing the development of educational software (Bialo & Sivin, 1990; Billings & Cobb, 1992).

These studies and reviews of the use of technologies in science education have shown primarily positive effects and thus have supported the proliferation of technical resources available in educational settings and have spurred the development of domain specific software. The implications of these research results have, for the most part, been content and equipment bound. However, they share common themes and identify variables that have become critical in reframing our expectations of the possible outcomes in science education (Bransford, Sherwood, Kinzer, & Hasselbring, 1985).

The uses of technologies as motivators of both teachers and students, students' attitudes, time on task, individualized learning, and student empowerment are all common themes which need further study in contrast to other resources or models of teaching. In addition, it is necessary to address common outcome goals such as critical thinking, science process skills, and problem solving abilities which are emerging as key issues in the current crisis in science education. Tinker (1991) has posed some of these questions:

- What are the components of motivation for science learning that are effectively addressed by teaching and learning with technologies?
- How can the research on CAI and CBL inform classroom practice and other non-technology based learning experiences?
- Why is computer-based learning more efficient?
- Is this a lasting effect?
- Does this have implications for covering more content material or the same content in greater depth?
- Are students capable of sustaining this pace of learning while maintaining expected achievement outcomes?
- What are the roles for teachers in individualized multimedia learning environments?
- What happens to teachers and students in classrooms where students have access to more information than the teacher can readily command?

Although there has been a multitude of research in all disciplines about the impact, effects, and outcomes of the use of technologies for teaching and learning, little has been done to synthesize across disciplines the relevant instructional and learning variables that are significantly affected by the integration of teaching and learning technologies. There are insights from studies using technologies in literacy and language development, writing, social studies, and product development which could improve the breadth and depth of our thinking about possible uses of technology for science teaching and in science education research.

Research With Technologies

Computers have become important tools for the science education researcher. On-line literature searches, word processing, and desk top publishing facilitate the writing, editing, presentation, and production of printed manuscripts. Statistical programs, now available on personal computers, enable researchers to perform desk-top analyses on large data sets and increase the opportunities to explore a data set while decreasing the time required to see the outcomes of such explorations.

Previously, statistical programs provided traditional comparisons of quantitative data but programs are now available which facilitate analysis of qualitative data, e.g., identifying phrases, reporting word frequencies, and locating language patterns in transcripts and observation records. Graphics programs are used to create clear, colorful, and appealing visual displays of data which can be easily integrated with text.

Electronic mail, facsimile machines, and computer networks increase the frequency and possible links between professional communities. In some instances networks have been used to create *virtual* universities of educators and researchers around particular research questions, themes, or methodologies. These *virtual* communities may increase the frequency of discourse around particular ideas and provide opportunities to bring together researchers from around the world to address cross-cultural issues in science education. Although greatly underutilized for professional activity, computer networks, distance learning, and electronic mail offer tremendous potential as tools for the focus of study, for collaboration, and for productivity in science teaching, learning, and research (D'Souza, 1991).

Computers and multimedia interactive systems present not only new possibilities for classroom experiences but also offer researchers new windows into the interactions among students, students and curriculum materials, students and teachers, and teachers and curriculum materials (Dershimer, Berger, & Jackson, 1991; Freitag & Abegg, 1991). Perhaps for the first time, researchers can develop repeatable instructional treatments by using multimedia delivery systems. For research purposes, different types of learners can be exposed to different types of instruction in a controlled manner. Some variables affecting student achievement may be observed more closely by removing some of the variability of interpersonal interactions. Multimedia systems offer many possibilities for the development of a "case study" approach to science teacher/researcher preparation. Furthermore, these uses of technologies to "cut, shape, or put together materials" in new ways holds promise for the investigation of new questions and for new methods of research.

Research From Technologies

Science educators often follow scientists in applying new technologies. Scientists are currently using supercomputers to model complex systems and to develop multiple representations of concepts or theories. This is rarely done in science education. However, the availability of the "education Cray," large longitudinal databases, and competing models of science learning will make it possible for science educators to begin to use computers to develop models of complex systems (i.e., classrooms) and ideas. Such models can further research in science education by providing analysis of the significant variables within proposed models, identifying areas where critical data is missing, and predicting outcomes which might be testable in classroom settings.

Through the use of modeling, science educators might be able to compare different models of teaching and hypothesize their effect on students of different learning styles or predict outcomes of students' idiosyncratic approaches to content material. Models might be used in the development of meaningful assessment instruments and to extend or test theories of instruction and learning. Such explorations of models can lead to descriptive links between theory and practice in science education.

Research About Thinking With Technologies

This is perhaps the newest, most exciting, and fastest growing use of technologies in science education research. Interactive technologies provide new types of data which can be collected unobtrusively and in large quantity about the processes and outcomes of a learning intervention (Freitag & Abegg, 1991; Berger & Dershimer, 1992; Baker, Niemi, Gearhart, & Herman, 1990). Originally, data collected by computer were used to assess large numbers of students or to give students immediate feedback as they progressed through a programmed sequence of instruction. Through this mechanism students were able to try multiple strategies without "fe.r" of criticism. Students could be challenged, as they are in video games, to try again to improve their "score" in a learning game. Data could be used to provide individualized entry levels into an instructional sequence, thus eliminating or promoting review of specific material. Teachers could use the output score as a standard assessment of student achievement and comparison between students. Simulations could provide students with multiple opportunities to explore phenomena and in the process students could learn to control variables and thus influence the outcomes of simulated experiments.

However, this source of data has not generally been collected or interpreted. Interpreted results remain primarily in product development literature and have been used to form evaluations of software about age-level appropriateness, feedback styles, and comparisons with traditional instructional methods. Only recently have science education researchers begun to record and analyze electronic records of students' use of computer based instructional materials (Berger & Dershimer, 1992). The increasing use of multimedia software systems as instructional interventions affords researchers the opportunity to collect more data in greater detail, with fewer human hours than ever before. It is possible to collect much more data than could be interpreted by making use of software backdrops that record students' paths through instructional software, down to their time spent in any instructional component and their sequence of keystrokes. It is also possible to record the process an individual or group of students uses to create informative presentations within multimedia environments (Freitag & Abegg, 1992). These records can then be used in assessment, as evidence of cooperative learning, or to help students recognize and compare the relationships they create between related concepts. With access to new types of data, the challenge is to interpret these data meaningfully (Taylor & Shore, 1992). Dershimer, Berger and Jackson (1992) report "state maps" and electronically recorded "log files" of students' use of various components of a multimedia instructional package. By using software to create "maps" of students' use of software resources they were able to show similarities and differences among college students' learning modes. They were also able to suggest an increased use of "higher level" aspects of the software over time. Custom designed software tracking devices may increase the amount of data available to researchers by facilitating data collection from remote sites, by creating data sets for all types of computer-based interactive systems, and by removing the human observer of student interactions with instructional materials.

Managing Research With Technologies

As the available data about science teaching and learning increases, computers provide new ways of combining and analyzing large, complex data sets (Martin, 1991). Through multimedia environments, text, video, graphics, and pictures can be integrated into a single presentation and shared with colleagues. The many organizational software "utilities" can assist in organizing data collection, analysis, interpretation, and reporting. Telecommunications open the possibility that university resources can be accessed instantaneously from remote research sites. Researchers from around the world can collaborate in research on large scale problems, cross cultural issues, or specific themes. Just as students through "KIDS-NET" have managed to collect more data on acid rain than the United States Geological Survey (USGS) in several years, science educators can begin to use a multitude of sites connected via networks to collect relevant data across classrooms, schools, districts, regions, states, countries, and cultures.

One of the most exciting possibilities for managing research through technologies is linking researchers to funding agents and research sites. Agencies could use databases to make final reports and unpublished results more readily available. The trend towards funding large projects requiring the efforts of multiple researchers and generating large data sets or multiplier effects suggests that the use of computers to manage research will become an increasingly important aspect of science education research.

Conclusions

The roles for technology in science education can be described under the five part framework adapted from Sherwood (1984). As new roles for technologies in the classroom are explored there will be new possibilities for research. However, there is much that science education researchers could and perhaps should be saying to product developers, teachers, students, and their colleagues about the possible development and use of these technologies based on what is known about the nature of teaching and learning in science. Despite enthusiasm for research with a technology focus, there is little evidence that technologies are transforming the content or approaches to pre-service teacher preparation. For teachers to be prepared to experiment with new technologies in their classrooms, they must experience content, pedagogy, and research on learning as presented in part through the use of these technologies.

If technology is to extend "our abilities to change the world" as the authors of *Science for All Americans* (1990) suggest, then as researchers of science education we must make use of technology to "reach further with our hands, voices and senses" into the processes of teaching and learning science.

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Technology in the Service of Science Education Reform

Karen E. Reynolds

Current reform efforts in science education in California include the incorporation of technology. Technology is finding its way into curriculum, instruction, and assessment. These changes are influenced and supported by a variety of actions at the state level and notable progress has been made.

A focus on the roles of technology in science education is part of the current reform effort in California that has been formalized through the adoption of the new California Science Framework (1990) and the parallel development of comprehensive testing strategies by the California Assessment Program (CAP). The integration of technology in science in California schools is shifting from a hardware-centered undertaking to a student-centered enterprise. This shift, which is present in most curriculum areas, is reflected and reinforced by several trends:

- The use of computers, video equipment and other high tech devices have become common in our society. Teachers and students operate on more sophisticated levels with technology in their personal lives.
- Technology use in school settings has diversified: (1) kinds of technology used; (2) how it is accessed within the school site; and (3) ways it is integrated into instruction, management, and assessment.
- Funding for technology projects in education has shifted from supporting hardware procurement to promoting program implementation and instructional effectiveness.
- Professional conferences, sponsored by organizations like Computer Using Educators (CUE), that originally addressed problems in the management and technical possibilities of computers, and then expanded to consider different kinds of technology, now reflect an increased concern for diverse effects of technology on individual learners and on investigating cognitive processes within specific curriculum areas, including science.

The challenges and opportunities associated with incorporating technology in California science programs are varied and promising, respectively. And, because of the impact of technology on the success of science education in the state, they are unavoidable and welcome.

Curriculum Reform

A revitalized science curriculum is expected to (1) address real world concerns and involve the use of practical problem-solving abilities; (2) provide scaffolding to assist students in building conceptual knowledge that can be applied in different contexts and that is associated with major themes of integrated knowledge; (3) integrate the fields of science (life, earth, and physical sciences) and incorporate other subjects, such as language arts, mathematics, media arts, fine arts, and social studies. Technology is to be an integral part of the curriculum, both as a content component (societal issues, electronics, time/space relationships, and

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other areas), and as a tool for curriculum design and management.

Technology in Instruction

The use of technology in science instruction allows greater flexibility in instructional and assessment approaches than had been previously possible. Multimedia, simultaneously using more than one kind of technology, is accessible to the classroom teacher and easily operated by students. In addition, student use of technology in problem-solving and instructional contexts is essential to their preparation for our technological world.

Reform in science instruction has several thrusts, each of which is partially addressed by expanding the integration of technology. Science instruction must (1) allow students to learn in a variety of ways, recognizing that students have preferred learning styles and, at the same time, will benefit from developing a broader repertoire of learning strategies; (2) increase the use of collaborative learning, hands-on activities, community resources and other effective teaching and learning strategies; (3) consider the diverse backgrounds of students; and (4) improve self-esteem, and strengthen the relationship between motivation and success among all students, including minorities, ESL, and others at-risk.

A constructivist approach is encouraged to reform instruction in science. Hands-on experiences, discussions, group interaction and independent work allow students to construct, test and adjust their own understanding of specific science concepts. In this approach, it is recognized that students do not begin any unit of study or investigation without preconceived notions and experiential knowledge at some level. It also is recognized that knowledge constructed internally, in contrast to knowledge imposed externally, will persevere. Variations in content background, abilities, and learning styles make it imperative to establish an instructional setting with a variety of avenues for students to organize their individual thinking, make comparisons, explain and debate, and carry out other processes that allow them to confirm their understandings or make adjustments in their mental constructs. Technology provides powerful tools and resources for these processes.

Technology provides increased opportunities to provide the variety of experiences that are recommended for science programs. With computerized models, students can explore specific variables, form and test hypotheses, and construct generalizations. Events on video can be viewed repeatedly, at different speeds and in different sequences in order to study details or patterns. Having students videotape events may result in attention to phenomena that would otherwise be missed. The ease of accessing visuals from pictorial databases on videodisc and in CD-ROM better accommodates visual learning, the most common of learning preferences. Databases can be accessed from disks or through telecommunications services. Rapid output in table or graph form, with or without statistics, allows extended time for interpretation of data and for comparisons of results due to variables within the data. Students can organize observations by formatting their own databases. Communication can be enhanced in many ways including wordprocessing, desktop publishing, graphing data, diagramming, audio recording, using telecommunications, and sending or receiving FAX transmissions. Temperature, light, sound, and other evidence of energy can be monitored over short to long periods of time, making a new genre of experiments available to students at all grade levels.

As students use technology in science for producing, investigating, problem-solving, information gathering or other activity, the hardware itself becomes transparent, or invisible, allowing students to focus on their own tasks. Thus, students are "doing science" rather than "using computers" or "operating equipment." Technology is expected to take on an expanded and more varied role in science education as new uses of technology are developed for instruction. The associated experience with hardware, software, and tools becomes more relevant in students' educational experience as society as a whole reflects greater dependence on technology in the daily lives of individuals.

Technology and Assessment

It is recognized that reform in instruction must be accompanied by reform in assessment. Assessment in science must be varied and on-going in order to adjust lessons to student progress and to emphasize individual growth, rather than comparison to an arbitrary standard. Assessment must also be multi-faceted in that a variety of strategies are employed. Teachers can gather information about students' understanding of science concepts through demonstration, discussion, responses to specific questions, representation of knowledge through drawings, drama, written projects, student produced videotapes, performance tasks and other means. Long term progress can be measured by comparing work collected in portfolios as well as periodically testing for specific knowledge. Records of student progress will necessarily also be varied, including criterion referenced grades, checklists of observed skills and demonstrated understanding, individual descriptions and anecdotes, and portfolio summaries, in addition to traditional test scores.

Assessment should be carried out at various levels including monitoring individual student progress, evaluating program effectiveness and analyzing teaching behaviors. Technology provides tools for productivity, vehicles for maintaining records, and windows for observing student behaviors. For example, the video camera can record ephemeral events (oral report, role playing, science display, or active demonstration) for storage in a portfolio. Videotaping also allows teachers to analyze classroom dynamics. Teachers rarely have time during class activities to appreciate interactions between individuals or nonverbal behaviors that reveal learning or thinking. Teachers who videotape in their classrooms are impressed by the power of the technique in helping them, in addition to checking student progress, to analyze their own teaching and to become researchers in their own classrooms.

The California Assessment Project (CAP) is developing a variety of instruments for statewide testing that include performance tasks and open-ended writing to provide balance to the traditional paper and pencil test. Greater emphasis is being placed on thinking processes in science and conceptual understanding in place of recall of "basic facts." The potential of video images presented through videodiscs, videotape, CD-ROM and other means, make serious consideration of pictorial approaches to testing inevitable.

Computer Literacy for Teachers

With the dramatically increased use of computers nationwide, reports by teachers in science have placed emphasis on computers' value in motivating students and in promoting positive attitudes (Becker, 1991). This centering on the affective domain may reflect more teachers' abilities to evaluate these effects (i.e., it is obvious that students enjoy using technology but not so obvious how it contributes to analytical thinking) than providing an accurate picture of the benefits in learning to the students. For teachers, computer literacy, which once referred to facility in operating hardware and software, now includes the ability to analyze thinking processes and levels of learning (cognitive processes and consequences) that result from student uses of technology. In science this is particularly important because of the emphasis on investigative approaches, collaborative efforts and development of independent learning skills.

Technology and the Instructional Environment

Reform in science invites teachers to shift from the role of dominator to that of facilitator, and to transform the classic teacher-centered classroom into the more complex but effective student-centered learning environment. Teachers will use their expertise more extensively as they plan for multiple outcomes, monitor progress, respond spontaneously, and moderate discussion in such a constructivist climate. For teachers, judging the best balance between guidance and choice, exploration and summarizing, and the different modes of learning requires different educational decisions than does carrying out direct instruction. Technology is a partner in this enterprise.

Both computer labs and computer stations in classrooms are included in comprehensive technology plans. Computers in science labs are used for gathering, organizing and analyzing data. Exploratory and experimental setups can be used for repeated tests or monitored over long periods of time using interfaced instruments such as temperature probes and light and sound detectors.

Through telecommunications, the science classroom is extended beyond the school and local setting to take advantage of resources and contacts throughout the state, country and even world. Students participating in programs such as National

Geographic Kids Network explore science concepts and related social issues as they interact with distant peers who make world perspectives become real. Carrying out on-line searches through services such as Dialog's Classmate allows customizable information retrieval from resources not otherwise available at a school site.

A lesson is a segment of instruction, not a period of time. Some lessons are carried out in a standard instructional period of 45-50 minutes, some over several days. Some assignments may be extended over a long period of time or be connected to work carried out by students in other locations or time periods. For example, in establishing and using databases, information gathered by students at one time can be retrieved later for review or for a new purpose: shared with students in other schools or accumulated over years for long term studies.

Logistics to accommodate equipment are manageable and well worth the effort. Technology operation is mastered quickly by students who can teach each other. Teachers do not need to be techies so much as facilitators in a technology enhanced classroom. Small group video and computer stations are often set up so that students can work at their own pace and share facilities on a rotational or demand basis. Some equipment is often mounted on rolling carts to allow use in different locations.

With emphasis on conceptual learning rather than mastery of a standard set of facts, specific topic coverage can be arbitrary. Teachers have flexibility in developing interdisciplinary units and latitude in providing opportunities for students to pursue individual interests and to be assessed on individual progress.

State Level Influence and Statewide Support

A number of actions have provided short term or long term support for technology in education in California, actions that also helped precipitate effective integration of technology in science. Computer Using Educators (CUE), which began as a grass roots organization, was instrumental in this and continues to maintain a leadership role in disseminating information and forming educator networks. The establishment of quality standards and evaluation procedures for screening software and video materials, now sponsored by the Department of Education, began with CUE. The resulting Software and Video Clearinghouse now has begun to evaluate CD-ROM discs and videodiscs in addition to software and videotapes. CUE sponsors two well-attended state-wide conferences each year.

Resource guides to exemplary software and model instructional units have been developed in the major subject areas, including science (1986), through state funding. An updated publication of model instruction units that integrate technology in K-12 science is in progress (Reynolds, in press). State funds also established regionalized technology training centers for teacher in-service, responsibilities now assumed by county offices of education and California Technology Project Regional Consortia. The Science and Technology Units within the state Department of Education have cooperated in supporting the development of model software programs and in the purchase of specific software and equipment for the public schools in California.

The California Technology Project (CTP), a partnership project of the California State University (CSU) and the California Department of Education, maintains the Technology Resources in Education (TRIE) electronic information service for K-12 students and teachers. TRIE provides subscribers (at no fee for students and teachers) with electronic mail, computer conferencing, on-line databases, bulletin boards, and access to the Internet. Users connect to TRIE through Regional Consortia nodes or CSUNet. A recent survey (Blurton, 1992) revealed that 65 percent of the over 4200 TRIE users are teachers with more than six years of experience, demonstrating that a large cadre of technology users are in place in the schools. The Association of State Technology Users in Education (ASTUTE), another outgrowth of CTP, represents, trains and informs faculty in colleges of education of the twenty campus CSU system.

State-mandated computer education requirements for teaching credentials have been in effect since 1988. Higher education institutions have chosen a variety of strategies that allow teacher candidates to meet the requirements within credentialling programs. It is interesting to note that although separate, specialized technology courses exist in most of these programs, faculty members are increasingly integrating strategies for using technology in their curriculum and methodology coursework and requiring students to actively demonstrate the ability to use technology with children during teaching practice. New teachers with recent training in technology are often leaders in innovation early in their careers as educators.

Significant assistance for inservice teacher training in the integration of technology in science was provided by CTP through the 1991 Science Technology Leadership Academy (TLA) in which 60 representatives of CTP Regional Consortia and California Science Project (CSP) sites participated in a trainer-of-trainers model for state-wide inservice. TLA participants experienced, practiced and refined strategies (Reynolds, 1991) for helping teachers integrate technology in their classrooms that would result in K-12 students engaging in investigative science. These trainers, in turn, facilitated inservice training for K-12 teachers in their respective areas. Many TLA participants are continuing to carry out inservice programs that promote technology in science. Other science projects, such as the California Science Implementation Network (CSIN) and Project Storyline provide opportunities to address the integration of technology in school science programs.

A metamorphosis has taken place in the development of commercially prepared instructional materials. The California guidelines for the 1992 state adoption of science materials has placed an emphasis on the inclusion of multimedia components in K-12 instructional packages. The major publishers have responded by producing computer software, videodiscs, videotapes, and audio tapes to accompany their text series and activity kits. The instructional approaches and interdependence of the components vary among the submissions, but the precedent of multimedia science support has been set and there will never again be sole reliance on the printed textbook. Because of the economic importance of California as a consumer of educational products, California adoption guidelines serve to drive the design of science instructional materials available to the nation.

Conclusion

When integrated in school science programs, technology helps students develop positive attitudes toward science, skills in scientific thinking, structures for conceptual knowledge, capacities for learning independently, and abilities to make decisions from global perspectives. Successful science programs encourage students to consider science related careers or to capitalize on individual potential.

California schools have made notable progress in procuring hardware and software for a variety of technologies, integrating the technology effectively in instruction, adopting appropriate organizational techniques, embracing alternate assessment strategies for crediting student achievement, preparing teachers to effectively use technology, and optimizing other opportunities that ensure success for all students. In spite of these accomplishments, there is still great need for expansion and growth in each of these areas. These actions are still considered innovations in many schools and districts, and adequate equipment and facilities are not yet accessible to the many teachers and students who are otherwise prepared to use them in their science programs. It is recognized that technology is not, by itself, the answer to improving science in the schools. Technology is part of the assemblage of possibilities. The answer lies in how the possibilities are balanced. Nevertheless, technology is contributing significantly to reform in science education, and California is perceived by other states in the nation as a leader in this effort.

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Technology Expands Science Instruction in the Elementary School

Conrad P. Mezzetta
Lyn Chan

Technology Optimizes Performance in Science (TOPS) is one of seven curriculum-focused projects funded by the California Department of Education to disseminate their instructional strategies and materials which model the new state curriculum frameworks as well as the use of technology in the instructional process. TOPS is designed to improve science instruction in grades K-6 by matching the most appropriate teaching methods and technology with framework-aligned curriculum. Technology-based and hands-on activities focus on cooperative learning strategies to involve all students in exploring science and improving their understanding of the major science strands. Computers, ITV, videocameras, interactive videodiscs, robotics, and telecommunications are extensively used for special activities as well as regular classroom instruction. Printed materials are supported by diskettes. TOPS coordinators can assist schools to assess their resources and needs, to plan and implement staff development, and to install a science program that takes advantage of available technology.

> The hurricane was 385 miles wide. There were constant winds of 130 m.p.h. The highest gust was 174 m.p.h. Hugo was pushing a wall of water 12-18 feet high. We heard about a woman who went back to her home after the storm and found a live dolphin there. Beside the flooding and hurricane winds, there were many tornadoes. You could tell where the tornados had been because the trees were twisted.

This description of Hurricane Hugo which devastated South Carolina was received at Skyline Elementary School in the South San Francisco Unified School District on October 5, 1989, via modem and phone line. Students at Pinewood-Summersville Preparatory School in Summersville, South Carolina had sent this vivid message to other pupils nationwide participating in an introductory telecommunications unit. Shortly thereafter Skyline's students reciprocated with a report of the earthquake of October 17, 1989. Since that time, fifth and sixth grade students have continued to network with their counterparts across the country to exchange information about their school and neighborhood and to explore the global phenomena of weather and acid rain.

Although telecommunication reflects only a small fraction of the varied technologies used to teach science at Skyline (e.g., interactive video, robotics, videocamera, digitizers, CD-ROM, and probeware), it is representative of the school's vision of teaching science as well as its use of educational technology. Teachers view technology as an effective way to nurture the application of the constructivist model for learning throughout the instructional program (Hurd, 1990). Students are encouraged to work on individual and group projects that foster creativity, autonomy and communication. Huddled around their computers equipped with modems and interactive science software, students are able to investigate real world problems and to learn how to collect, process, validate and apply important data.

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School Commitment to Innovation

Skyline is a K-6 elementary school serving an ethnically and culturally diverse population of 528 students from largely middle socioeconomic homes. The school's ethnic breakdown is as follows: Asian–17.4 percent, Pacific Islander–6.1 percent, Filipino–46.4 percent, Hispanic–9.8 percent, Black–7.1 percent, and White–13.2 percent. Twelve percent of the school's students have limited English proficiency and 54 percent come from homes where a language other than English is spoken. Students tend to score well above district and state norms on tests measuring achievement in basic content areas (i.e., math, language and reading).

In the early 1980's the teaching staff at Skyline pioneered the use of microcomputers in the classroom and through the years the school has continued to serve as a model for others, within and outside the school district, in the use of technology to strengthen and enrich curriculum. A milestone in implementing technology-based, innovative educational programs at Skyline was the development and dissemination of an exemplary AB 803 project, CompuTHINK, from 1984 to 1987. Staff of adopting sites were trained to develop a problem solving curriculum to enhance thinking skills and to devise problem solving strategies that would transfer to all subject areas. Technology-based lessons included the use of simulations, databases, word processing and LOGO.

Model Technology Schools

Beginning in 1987, the school staff made a major commitment to improve science instruction. Under the leadership of several energetic and creative teachers and with support from the district, the instructional staff designed and submitted a proposal to the California Department of Education (CDE) to develop a Level II Model Technology Schools (MTS) project. Skyline's MTS project, Technology Optimizes Performance in Science (TOPS), was one of ten Level II developmental grant proposals funded under AB 803. After two years of development, TOPS was reviewed by the Science and Mathematics Division of the CDE. Of the three science developmental sites reviewed, two (TOPS and a middle school site) were certified as curriculum aligned and subsequently funded for dissemination (Nakagiri, 1989).

Technology Optimizes Performance in Science

AB 1470, enacted into law on January 1, 1990, funds a full-time coordinator and a part-time consultant to maintain a model site for visitation and training and to provide direct consulting services and materials to those schools adopting or adapting TOPS strategies and practices. Visiting educators, some from as far away as Japan, Russia, and Denmark, have the opportunity to view teachers integrating technology in multiple ways and to consult with them on the use of technology to supplement more traditional hands-on science activities. Use of the TOPS project by postsecondary institutions, the CDE, and other educational agencies to conduct research as well as the many visitors are a deep source of pride for the students and the entire school community.

Over the past two years, Project TOPS outcomes (products and services) have been actively disseminated through publications, conferences, and workshops in conjunction with the California Science Project, the California Science Teachers Association, the CDE, technology networks/organizations, and regional and local educational agencies. Forty-five projects adapting TOPS have received School-based Educational Technology Grants from the CDE to acquire technology equipment, instructional materials and services to strengthen and support science instruction. The TOPS staff assists other schools to develop plans that are aligned with the California Science Framework, identify adequate staff-development services, and provide for the evaluation, acquisition, distribution, and on-going access to and use of learning resources which support the instructional process.

Project Goals

The major goals of the TOPS project are to: (1) improve student achievement and knowledge in science, (2) develop students' critical thinking and problem solving skills within the science curriculum, (3) stimulate student interest and motivation in science, and (4) demonstrate to teachers through cooperative planning, modeling, and coaching the benefits of using technology and direct experience to support science instruction.

In support of these goals the project staff has devised a number of strategies to help schools plan and implement a science program that closely follows the California Science Framework (California Department of Education, 1990). Schools are encouraged to develop a science program that:

- provides a balanced curriculum in the physical, earth and life sciences and makes connections among these science disciplines;
- engages students in a variety of active experiences using traditional science materials, educational technology and school-wide events;
- emphasizes development of conceptual understanding and higher level thinking processes;
- organizes an articulated scope and sequence at the school level;
- uses tangible, real-life experiences which connect to the real world of all students;
- nurtures positive attitudes for learning science by helping students develop rich and meaningful understandings of the phenomena they encounter; and
- makes extensive use of community resources. (pp. 160-161)

A Day in the Life of a Project

Skyline teachers take full advantage of available technologies to create a wide range of learning opportunities for their students. The following scenarios provide a kaleidoscopic view of the TOPS program. It is a representative rather than a comprehensive view of the teachers and students as they actively explore science. The best way to understand the culture of the school is to visit the site.

It is Thursday morning at 7:30 a.m. and a truck from the scavenger company picks up three bins full of recycling materials–white paper, newspaper and aluminum cans. As a school-wide focus, the students have been learning the importance of conservation and recycling. On Fridays student monitors go around to the classrooms collecting recycling materials. When the bins are full, the company comes to get them. And the cycle continues.

At 9:50 through the PA system, we hear the chimes from a xylophone signaling the beginning of the Radio Club presentation from a group of speech students, each with a different speech impediment. We hear the weather report, special interest news about a particular U. S. president, a science information item and coming events related to the activities of the student body. Students are encouraged to participate in a jingle contest. Winners will be acknowledged and rewarded for their endeavors.

Wilt Wong's Atom's Club arrives on site to present to several classes in third through sixth grade hands-on activities related to life and physical sciences. These high school students will come several times this year as they have done in the past. Today they will present Field Biology. Students relate to these high school scientists as models. While they do lesson presentations, a camcorder attached to two wide-screen monitors is set-up to record the event as well as to project the activity on the screen for a better view. Students who are absent can borrow the videotape to take home to view the lesson they missed.

Meanwhile, in kindergarten, students in fifth and sixth grades give up their morning and lunch recesses to work with the little ones on the computers. Using the *Children's Writing and Publishing*[1] program, the older students take dictation of stories which are then printed. Mrs. Richardson, at a later time, has students share their stories. Other students read their classmates' creative writing aloud in the group circle. The students then take their work home to share with their parents.

Later in the day, a laser disc player with the wide-screen monitor becomes the center of interest. The kindergartners will view a program on sink or float. The visual images are so powerful that they draw children into learning situations. Students explore the problem of objects floating or sinking. Using Optical Data's *Primary Windows on Science* laser disc program, the class first makes predictions, then tests their hypotheses using hands-on activities. From observation of the students' reactions, it is clear they have been able to verbalize the process and are able to use science words appropriate for that particular investigation.

With pitchfork in one hand and a bag of produce in another, Mrs. Moody leads the first grade students to the compost bin. A nearby grocery story has donated their throw-away produce to the school's Life Lab program. Today, the students will discuss the easiest and most practical way of improving the soil by re-using old vegetables and rotting fruits. As each fruit or vegetable is added to the compost bin, students identity that particular object. This is a good way for students to learn the names of foods. They also discuss decomposition and the role of microorganisms in the breakdown of the waste. The students will keep track of this process by bringing the portable computer to the compost bin. It is hooked up to probeware to take temperature readings and is used as well to record students' other observations. A chart and graph software program will be used to record the temperature data.

Mrs. Kaiser's second grade students just finished linear measurement in math. To expand upon their experience, the students load the *Measurement, Time and Money* program from the file server of the IBM network. Today, they will measure objects on the screen. With the audio capabilities of the program, they are given quick reinforcement of how well they are doing. They also see stars on screen as rewards as they proceed from activity to activity. Using the database application of the program, they collect objects, measure them and record the information. This will be printed in two forms–database and graph form.

In Mrs. Soules' first and second grades combination class, the students have been studying about turnips in reading. This ties with the science content for the quarter. Using *Linkway Paint* program, students illustrate what they have been reading about. With tools from the menu, they create their folder, select drawing tools, decide what colors to use and begin their artistic illustrations. With colorful graphics, they add buttons to make connections to pages on which certain objects have been added. Students are able to admire each others' work on the screen. These will be saved for display purposes for parents at open house.

Mrs. Larson's third grade class has been studying cells. After the initial introduction, students use *ITV Bioscope* to further their knowledge. They then go to room 10, a comfortable carpeted room, for a lively discussion as they view the diversity and similarity of cell images from a life science laser disc.

Using the *Structure of Life* module from the FOSS Project, Mrs. Neville's third grade class puts the basics of how plants grow into practice. After growing seeds in a seed sprouter, the students prepare the soil and transfer seedlings to the planter box in the courtyard. Students continue to measure and record data as they observe the plant growth. They watch time-lapse photography on plant growth from the laser disc which will help them to sharpen their abilities to make observations.

Fourth graders have started their *Acid Rain* telecommunications program from the National Geographic Kids Network. One of the schools in their group is in Japan. Students are full of questions about them. What's their school day like? Do they go to school from sunrise to sundown? When do they have vacations? Do they have lots of homework? How do they spend their free time? How often does it rain? Do they have a drought like California? The students use the word processor capabilities of the telecommunications program and start writing. Their letters will be merged, addressed and sent to their Japanese counterparts via E-mail.

Some fifth graders have finished with life science and are ready to embark on physical science. With *Energy Causes Changes in Matter* as the school's unifying concept, they focus on the fifth grade level concept: energy moves objects. To have a better understanding of controlled motion by controlling the energy input, Mr. Ralston introduces the lesson with *Big Trak*, a robot programmed to move through a maze of orange cones. Students review left and right turns and estimate how many forward steps it takes to move the robot through the maze. As they expand discussion on how machines work, these students will review the commands of the *Logo Writer* program, something they learned in the fourth grade problem solving class. They will use the computer as a controller to operate *Lego Technics* while continuing to build problem solving skills. They construct machines using *Lego* pieces and use the *Lego TC Logo* contraptions to bring them to life. As students explore these exciting classroom-appropriate Lego and LegoLogo activities, they will create non-traditional Logo projects, utilizing experimental mathematics, videodisc control, Logo ensemble database and spreadsheet activities. Emphasis is placed on rich activities which promote opportunities for problem solving, embellishment and self-expression.

Fifth graders in Mrs. Saylor's class use *HyperCard* to create a class-profile booklet. Mrs. Saylor has obtained a Macintosh LC through a grant from the Peninsula Foundation. In conjunction with *HyperCard*, the students will use the still video camera and digitizer to capture student images which will be pasted on Hypercard stacks containing data about.the students. Students also use the scanner to add their choice of graphics to enhance their individual card. Buttons, buttons and more buttons linked to text and pictures are added in order to navigate through the electronic booklet.

Meanwhile, sixth grade teacher Ms. Lowry is collaborating in the pilot test of a global education program. San Francisco State University (SFSU) master's candidate Jean Goldberg, assisted by Dr. Sterling Bunnell, has designed: *You, Your Community, and the Natural Environment: Design for an International Student Video Exchange*. The purpose of this program is to develop friendship and communication between children in different cultures and to increase their understanding about ways of maintaining a healthy environment. Students learn how ecosystems work and gain experience with various hands-on ecological activities, such as the model balanced aquarium, soil profile, mini-compost, seed germination, micro-climate planter experiment, and field trips to the pond and marsh land. Video reports are done using camcorders to document what the students have done.

Six months ago contact was made with a teacher in Brazil to exchange these videos with those from her school. Sixth grade students have become familiar with using the camcorder by doing interviews and creating a *Getting Acquainted* video which tells about Skyline. The video experience has engaged students as they learn about a different culture and environment. Teachers and students communicate and work together to plan, discuss and share their work with peers in other countries (in this case Brazil). In addition to the camcorder, students use computers for word processing and newspaper publishing as well as using ITV programs and probeware.

What a way to get support in the elementary school from post-secondary education! College and university students can gain valuable field experience through collaboration with teachers. Concurrently, Skyline's classrooms provide fertile grounds for colleges and universities to carry on research and to pilot instructional materials.

Students from ESL are eager to come to the science lab to continue with hands-on experiences. While expanding their oral vocabulary, they will also be using technology to learn more about science. There will be a bee dissection today. Using the microscope for a closer observation of the body parts, the students are amazed to see that bees have five eyes! They describe what they see. Compound eyes? What reflections!! The students are then asked to simulate pollination by using the back of the abdomen to brush the pollen from a flower specimen. Following these experiences, students will view the *Dances of the Bees* from Scholastics' *NOVA: Animal Pathfinder*. Two students from this class have been instructed how to hookup the laser disc player to the computer in order use this interactive program. The students search for specific topics relating to bees from the menu. Students then use the *Children's Writing and Publishing* program to write about their experiences and knowledge about bees. Their printouts will become part of their portfolios. What a way for quick assessment!

Ms. Bechthold's Tutorial Learning Center (TLC) students come to the IBM lab to use *Stories and More*. Before they get to the stations, their curiosity causes them to stop by the crayfish tub to see what interactions are taking place. Two females have been added to the habitat. And they seem pretty active! In the meantime, an aquarium with 41 little crayfish enables curious eyes using magnifying lenses to see creatures frolicking among the elodea. My, how fast they grew since they were first seen attached to their mother's swimmerets. There are other containers of living things which are of interest–earthworms, Mother of Thousands (asexual plants), mealworms, amphipods. The students move to the computers to start the pre-reading activities before reading *Seeds* from the vast selections of stories in *Stories and More*. First they adjust headphones so that they can follow directions and actively participate in the program. Going through the process prescribed in the program allows students to self-pace according to ability. Open-ended questions encourage writing. The TLC aides come around to help facilitate. Progress is immediate and dramatic.

It is 2:00 p.m. and fifteen 5th and 6th graders meet with their Video Club advisor and speech teacher Ms. Strucinski. Today, they will be using two VCR's to edit the video tape they made about the Life Lab program so it can be shown on the local cable TV station. One group with the help of Mrs. Strucinski decides which portions of the tape to use to keep it to a maximum of three minutes. On the computer, the talent group uses the *VCR Companion* interfaced with *VideoOverlay Card* to make title and credits. Connecting the pieces results in a satisfying product for airing.

Training and Support for Adopting Sites

In keeping with the implementation guidelines of the new *California Science Framework* (California Department of Education, 1990), a science committee representing teachers from each grade level at Skyline School was organized in the fall of 1991. We wanted to address the question: What do we want Jack and Jackie to know about earth, life, physical, and health science by the time they leave 6th grade? Before each quarter begins, teachers meet to formulate the unifying concept for the science strand that will be the quarter's focus. In addition, grade level concepts and contents are formulated. Technologies are infused where possible to enhance lesson presentations. Special emphasis on the design of collaborative efforts for participants is encouraged. This process enables us to articulate a balanced and appropriate science curriculum throughout the school.

Successful TOPS adoption requires the same careful planning as well as organized training for teachers. A minimum of 3-5 days of training is required to successfully implement TOPS. The amount of training depends primarily on the staff's level of readiness and the technology/science equipment available to the school (Papert & Tinker, 1989). Professional development is designed to be flexible and adaptable to varied needs of elementary schools. TOPS inservices train adopters to:

1. Assess the alignment of the school science program with state standards.
2. Determine staff interest and needs to implement Project TOPS.
3. Select, acquire, and organize appropriate technology and science instructional materials, supplies and equipment.
4. Implement TOPS activities/technology: Special Events, Auditorium Shows, and integrating specific technologies into the science curriculum (e.g., videodisc, robotics, telecommunication, scanners, and digitizers).
5. Monitor and evaluate project outcomes.

To help adopting schools develop a better understanding of implementing a technology and activity-based science program, one or more workshops are usually scheduled at Skyline School. One-day or half-day workshops are provided for school sites adopting specific project components, e.g., use of probeware, videocam, followed by classroom-based support such as peer coaching and collaborative lessons.

Project Developed Instructional Materials

Strong commitment from Skyline's teaching staff enabled the project leaders to complete a variety of products to help teachers at other schools enhance the quality of instruction and to make science education more interesting and enjoyable for all students.

The Project Implementation Guide which contains information on the the selection, acquisition and use of technology is organized into six separate booklets: (1) Auditorium Shows, (2) Special Events, (3) Technology Lesson Plans, (4) Teacher's Resource Guide Database, (5) Creating Videos in the Classroom, and (6) Awareness Packet. Most of this information is also available in disk format. These written materials are supplemented by five videotapes.

Auditorium Shows

These weekly lunchtime shows, coordinated with a bulletin board and display area, pique student interest in science concepts studied in the classroom. The programs begin with a highly motivational event such as the presence of an alien demonstrating science themes or concepts. In addition to their interactive involvement as an audience, students participate in the staging of each production. The Auditorium Shows address most of the science strands. There are scripts for approximately thirty shows.

Special Events

Special events were designed for implementation on a schoolwide basis. They provide an opportunity for students to become creatively involved with both science content and processes. These activities encourage students to become active learners, to improve their critical thinking and problem solving skills, and to work cooperatively with other students. Events such as the Science Olympiad, Science Fair, and Science Activity Calendars demonstrate the value of cooperative learning, encourage students to use science in the real world, and facilitate sharing of student research and discoveries with parents. The booklet contains procedures for implementing nine different special events.

Technology Lesson Plans

This portion of the Implementation Guide contains descriptions of technologies that have proven especially effective in extending the range of experience available to students and teachers and includes: videodisc technology, computer probeware, LEGO and LEGO LOGO robotics, telecommunications, camcorder technology, computer simulations, computer databases, ITV tapes, and general science software. These tools can empower students to explore major ideas, to construct their own knowledge, and to generate and test models based on content that is real and meaningful to them.

For each technology the Guide provides: (1) a brief description of its advantages in the classroom, (2) possible applications, (3) services and costs of exemplary software and services, and (4) practical teaching strategies and lessons.

Teacher's Resource Guide Database

This database provides the teacher with a convenient source of information to acquire services, instructional materials, and equipment to implement project developed activities. The Resource Guide Database contains information on assemblies, books, field trips, films, peripherals, publications, science equipment and materials, software, speakers, teacher's science resources, telecommunications, video, and summary of all the resources.

Creating Videos in the Classroom

Designed for workshop presentations, this booklet provides the teacher with information on equipment and production of videotapes. Sample documents and forms include: video club flyer, application and acceptance letter, parent and teacher permission forms, release form, story board, edit log, and an evaluation questionnaire for students.

Awareness Packet

This 25 page booklet consists of sample materials from the Auditorium Shows, Special Events, Technology Lesson Plans, and Resource Guide Database.

Disks

The Auditorium Shows, Special Events, and Teacher's Resource Guide Database are available on 3.5" disks for the Macintosh. Files can be accessed using two applications: Microsoft Word and MacDraw.

Videotapes

The written materials are supplemented by five videotapes. The *Project TOPS Overview* videotape presents the schoolwide strategies and activities employed by Skyline School which successfully model the use of technology in science instruction, K - 6. Teachers and students are shown as they use technology and science equipment and materials to explore science concepts. (Audience - general, 9 minutes in length)

The *Inservice Training Series* videotapes present classroom-tested ideas and tips for using the videocamera, videodisc technology, and computer peripherals. Examples are drawn from the physical, earth, life, and health sciences. (Audience - teachers, 3 tapes, 8-10 minutes in length)

The videotape, *Doing Yourself Proud* is designed to inform and motivate students preparing to participate in a science fair. Using student voices and presented from the students' point of view, the tape presents ideas and tips ranging from project selection to presentation and final judging. (Audience - elementary teachers & intermediate students, 8 minutes)

Project Effectiveness at Skyline

> You really know that students are motivated to study science when they ask if they can do science rather than art. Technology has increased students' participation in science tremendously. (Cradler, 1991)

This testimonial for educational technology is contained in the 1991 evaluation report prepared by Far West Laboratory for the California Department of Education. Data from surveys, questionnaires and interviews of students, staff, and parents indicate that the project helped students develop skills and confidence using computers, videocameras, laserdiscs, and robotics. The many hands-on activities, science fairs and other contests and special events created interest in science and promoted concept development. Students worked cooperatively with interactive technologies. The report adds that parent involvement in school-wide programs helped students and their families become more connected to the school.

Over 65 percent of students indicated that use of technology significantly improved a wide range of skills: problem solving, writing and reading. Most students believed their grades had improved as a result of using technology. The majority of students also enjoyed their classes more, especially science, after the introduction of technology. Other significant areas of improvement reported by students were: ability to work with other students, positive attitude toward school, and self-esteem.

Evaluations conducted by site staff as well as outside evaluators generally found that TOPS increased student interest and performance in science at Skyline School (Mezzetta, 1989). Teachers reported that the training and assistance from the project staff and colleagues increased significantly their use of technology and activity-based science instruction (Nakagiri, 1989). As their comfort level with technology and science improved, their roles changed from dispensing information to facilitating interaction among students and between students and natural phenomena. In contrast to initial use of technology to reinforce previous learning, experienced teachers now encourage students to explore on their own and to create their own products. Students seem to have more control and to take more responsibility for their own learning.

Vision of Technology

As technology moves inexorably forward, new developments in communications will continue to emerge. Technology hardware is becoming more powerful and less costly, resulting in more varied and stimulating software (Loucks-Horsely et. al., 1990). Multimedia with its rich, multisensory images is replacing print media. Technology at Skyline is not replacing teachers, but it is changing their role. Teachers are becoming counselors and facilitators concentrating on teaching for conceptual change and problem solving skills rather than teaching solely for content mastery.

EndNote

1. For additional information on products referred to in this article, contact Conrad P. Mezzetta, SSFUSD, 398 B St., South San Francisco, CA 94080.

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K-12 Earth Science Education in California

Greg Wheeler

Changes in earth science requirements for K-12 curricula have been significant since the 1983 passage of California Senate Bill 813. Model graduation standards, curriculum standards and the state science framework mandate substantial coverage of what most recently are called geoscience topics. The university systems in California now accept geoscience courses as preparation for entering freshman. The California State Commission on Teacher Credentialing has completed changes in multiple subject and single subject science credentials which in combination with teacher inservice programs should greatly improve teacher preparation in geoscience.

State Requirements

Since the beginning of our planet, geologic processes have shaped our environment. Although knowledge of our planet's workings and resources is essential, earth or geoscience education has been slow to find its way into K-12 curriculums beyond the rock identification sessions and dinosaur facts.

Earth science education changes evident in California today trace their roots to passage of Senate Bill 813 in 1983 which requires two years of science, including both life and physical science, in secondary schools. The legislation does not require a separate year in each area of science but most districts elected to create separate, one-year courses for life and physical sciences.

Model graduation standards published in 1983 proposed inclusion of earth and space science concepts within physical science courses and the 1985 Model Curriculum Standards for grades 9 through 12 picked up this theme. The graduation standards developed by the State Board of Education required students to study earth and space science topics such as plate tectonics, geologic resources, geologic hazards, remote sensing, and paleontology.

The California Assessment Program (CAP) developed exams to test the "fitness" of school educational programs. The eighth grade CAP tests began in 1985 and gave parity in coverage to earth, physical, and life sciences. These tests served to emphasize changes in educational expectations and resulted in considerably more earth science in grades seven and eight than was previously the case. For state budget and political reasons the CAP tests for grades six, ten, and twelve were not widely used before the program ended in 1990. The State Department of Education is now piloting new tests for grades five, eight and ten. These new CAP tests continue to emphasize equal treatment for earth, physical and life sciences.

The strong trend toward inclusion of earth science in K-12 curriculum is again obvious in the *Science Framework for California Public Schools Kindergarten Through Grade Twelve* approved by the State Board of Education in 1990. The *Science Framework* divides science into physical, life, and earth science categories. The earth science chapter includes discussion of astronomy, geology and natural resources, oceanography, and meteorology. It is obvious that in graduation standards, model curricula science frameworks and tests the State Board

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of Education has realized and published the importance of earth science education.

The Role of Universities

The state's postsecondary schools have been slow to recognize the major changes required of science education in our public schools. In July of 1988, the combined Academic Senates of the California Community Colleges, the California State University, and the University of California released a report outlining science requirements for incoming freshman. The report stated that all college bound high school students should take physics, chemistry, and biology. The only mention of earth sciences was in the questions and answers section where it was suggested that earth science should be taught in junior high as preparation for the "fundamental sciences." This document, *Statement on Preparation in Natural Science Expected of Entering Freshman* (1986), sent a contradictory message on earth science education in secondary schools. Caught between state frameworks (with guidelines that required earth science) and universities that wouldn't accept these classes as science courses needed for entrance, most school districts offered earth science only in junior high or to non-college bound high school students.

The quagmire created by conflicting standards is beginning to dissipate. In 1994, entering freshman at the University of California will be required to take two years of laboratory science and three years are recommended. Among the A-F requirements published in the University of California Preparing for Admissions document (1991), D reads ". . . laboratory courses in earth/space sciences are acceptable if they have as prerequisites or provide basic knowledge in biology, chemistry, or physics." The California State University policy of accepting University of California approved courses for admissions means that, by 1994, earth science courses will be accepted at all California public universities. The wording in the document is still flawed. The Far Western Section of the National Association of Geology Teachers (FWS-NAGT) tried hard to persuade the University of California Board of Admissions and Relations to Schools (BOARS), which prepared the document, to treat earth science as an equal to other sciences. FWS-NAGT pointed out the strong endorsement of earth science in the State Board of Education requirements. FWS-NAGT cited states like Montana and North Carolina that require earth science options for college entrance. The BOARS committee, which has never included an earth scientist, refused all requests to offer testimony on behalf of earth science inclusion. Nevertheless, the new admissions document does open a door too long closed. Well-designed geology classes or other earth science classes will now be college acceptable.

The importance of earth science education has been nationally recognized. A policy statement on the critical nature of earth science education was endorsed in 1987 and 1988 by earth science organizations and by the National Science Teachers Association (NSTA) and the Council for Elementary Science International (CESI) ("Importance," 1988). The Council of Scientific Society Presidents (CSSP) passed a resolution regarding the teaching of geoscience at the pre-college level in 1991 ("CCSP Passes," 1991). The resolution resolved "that substantial study of geoscience (e.g., astronomy, geology, soil science, oceanography, and meteorology) be made part of the pre-college curriculum in the United States' middle and high schools, and that its status as a laboratory science be acceptable for college admission along with biology, chemistry, and physics" (p. 4). It further states "geoscience shall be one of the themes for the teaching of science in the elementary schools of our country." There is a national consensus of science educators and scientists in general, that geoscience, the most modern term for earth science, should be a strong part of all science education. This national direction will continue to pressure California universities to regard geoscience equally with physics, chemistry, and biology.

Teacher Preparation

The preparation and credentialing of teachers in geosciences has been difficult. The 1970 Ryan Act established single subject credentials for teachers at secondary schools. Only life science and physical science credentials have been and are currently options for science teachers. Under current requirements, physical science teachers must be prepared to teach physics, chemistry or any of the earth sciences. This means that although earth science is treated equally with physics and chemistry by the State Department of Education guidelines and progressively better in university entrance requirements, teachers must still be prepared as physical science teachers with earth science merely a subset of their broader studies. This has resulted in universities constructing long lists of course requirements. These course requirements, called waiver programs because they have waived the National Teachers Exam (NTE) required for entrance to credential programs, usually take more than four years to complete and have few students. Only a few schools like CSU Bakersfield, CSU Sacramento, San Francisco State University (SFSU), and San Jose State University (SJSU) offer earth science options for physical science waiver programs. The result of these rigorous requirements and the historic lack of earth science interest in K-12 science programs is that few science teachers are prepared to teach these subjects.

There are several possible solutions to the credentialing dilemma. The California Commission on Teacher Credentialing (CTC) has been revising waiver program standards for life and physical science credentials. Revisions for both waiver program standards now contain language requiring preparation to teach for conceptual understanding about the planet earth, including natural resources and other earth materials, geomorphic and internal processes, natural hazards and environmental issues, and the history of the earth and its life forms. Some modification must be made still to allow students to complete required classes in reasonable lengths of time. The CTC is also considering changes in the Ryan Act which would collapse the life and physical science credentials into one science credential requiring depth of preparation or emphasis for students completing the waiver program in biology, chemistry, geosciences, or physics. This would abolish the former physical science waiver program requirement of preparation in chemistry, earth sciences, and physics. This seems long overdue. An earth science credential could result in more and better prepared teachers to address the state science framework earth sciences areas.

Perhaps the method of qualification chosen by most incoming teacher credential candidates will be the new Content Area Performance Assessment (CAPA) exams. The CAPA tests replace the National Teachers Examination (NTE). The CAPA tests include essay questions as well as multiple choice questions. CAPAs for life science and physical science credentials correspond to the new content standards governing waiver programs with the exception that the geoscience content is heavily weighted towards geology. Whether through a waiver program or CAPA, earth science teachers need to demonstrate great breadth. When final resolution is reached on the science credential structure, adjustments will need to be made in the CAPA exams.

Kindergarten through sixth and sometimes seventh and eighth grade instructors generally possess multiple subject credentials. Both the multiple subject waiver and exam have been recently revised to include earth and space science. The waiver guidelines for the multiple subject credential treats geoscience requirements equally with those in life science and physical science. These 1990 requirements are being generally interpreted to require at least one course in geosciences (Slaymaker, 1991). The CAPA for the multiple subject credential is twenty percent science and one third of the multiple subject science content on the CAPA is geoscience, with special emphasis on geology (S.C. Slaymaker, personal communication, 1992).

The significant increase in required geoscience content in K-12 classrooms requires substantial in-service opportunities to bolster the training of most teachers already holding credentials. The California State University (CSU) system has several important programs designed to provide both content and hands-on training in geoscience. Project Catalyst, at California State University, Fullerton, has developed a comprehensive earth science teacher enhancement program for middle and high school teachers. The Bay Area Earth Science Institute (BAESI) at San Jose State University (SJSU) has developed educational partnerships among academic, business and government agencies. BAESI focuses on secondary school teachers. At California State University, Sacramento, SCATS (Sacramento Committee for the Advancement of Teaching Science) brings secondary school science teachers to campus once a month for in-service training in all facets of science education. ESCATS at CSU Sacramento provides the same service for elementary school teachers.

Conclusions

The last decade has brought major changes in earth science education in California. The substantial inclusion of earth science concepts in K-12 classrooms requires more and better trained teachers in these classes. The state needs to reconsider the Ryan Act single subject credential requirements to provide pathways for earth science instructors to receive credentials without mastery of all physical science. Finally, the universities of California must continue to develop effective ways to retrain those already in the classroom.

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The Bay Area Earth Science Institute: A Practical Model for Improving Earth Science Education at the Local Level

Ellen P. Metzger

The San Francisco Bay Area Earth Science Institute (BAESI) is a comprehensive teacher training program which demonstrates the power of utilizing existing community resources to improve science literacy. BAESI was established in 1990 with support from the National Science Foundation, San Jose State University, and a consortium of partners from academia, government, and business. The program promotes earth science, with its interdisciplinary nature and relevance to everyday life, as an ideal tool for attracting more students, particularly under-represented students, to science. The Institute offers a year-round program for all San Francisco Bay Area teachers (K-12) which begins with a month-long summer workshop at San Jose State University. Follow-up workshops, newsletters, and a resource center from which maps, rocks and minerals, videos, and activity books can be borrowed provide on-going support. The BAESI program serves as a catalyst to bring teachers, district administrators, university faculty, businesses and government agencies together in a coordinated effort to improve the quality of precollege earth science education.

Earth Science and Science Education Reform

National and state-level plans to improve science education are essential, but if significant and lasting improvements are to be made, local and regional programs must provide teachers with necessary training, resources and confidence to implement change. The Bay Area Earth Science Institute (BAESI) is such a program that puts state and national recommendations for improving science education into action.

The teaching of science as a catalog of isolated facts is a commonly recognized weakness of existing approaches to science education (Johnson & Aldridge, 1984; California Department of Education, 1990). *Science for All Americans*, (Rutherford & Ahlgren, 1990), the widely-cited report of Project 2061 of the American Association for the Advancement of Science (AAAS), emphasizes "meanings, connections and contexts, rather than fragmented bits and pieces of information, and... favors quality of understanding over quantity of coverage" (p. xv). The report recommends a thematic approach to science teaching that prepares all students to make informed decisions based on a understanding of their world.

The Scope, Sequence and Coordination (SS&C) project, proposed by Bill Aldridge, Executive Director of the National Science Teachers Association (NSTA) and funded by NSF and the Department of Education, calls for the teaching of every science, *including* earth science, each year during a six-year period. The SS&C model replaces the traditional "layer-cake" curriculum in which students take biology in the 10th grade, chemistry in the 11th and physics in the 12th with a more coherent approach emphasizing discipline-bridging themes such as evolution, energy, patterns of change, scale and structure, stability, and systems and interactions (Barinaga, 1990). The use of bridging themes forms an integral part of the new *Science Framework for California Public Schools* (California Department of Education, 1990).

A basic premise of the Bay Area Earth Science Institute (BAESI) is that earth science is an ideal tool for improving science instruction because it is

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an interdisciplinary science incorporating physics,chemistry, biology, mathematics and history. As such, it is uniquely suited to a thematic approach. For example, virtually every aspect of the earth sciences can be related to the theory of plate tectonics including the evolution of the earth through time, relationships between landmass configurations and climate, and the distribution of earthquakes, volcanoes and energy resources. Earth science also deals with timely and important issues such as landslides, waste disposal, and mineral resources; every community has earth science-related issues that are relevant to the everyday lives of students.

In December, 1990, the Council of Scientific Society Presidents (CSSP) passed a resolution regarding the teaching of geoscience at the precollege level. The resolution, endorsed by 60 CSSP members representing a combined membership of 1.4 million individuals in science, mathematics, and education ("CCSP Passes," 1991), urges that substantial study of the geosciences be made a part of the precollege curriculum in middle and high schools, that it be acceptable as a laboratory science for college admission and that geoscience shall be one of the themes for teaching elementary science.

Unfortunately, most precollege science educators are unprepared to teach earth science in spite of a widespread and growing recognition of its importance in the K-12 curriculum. BAESI was founded on the assumption that given opportunity and incentive, many Bay Area teachers would elect to participate in an intensive earth science training program. In the first two years of the program, 66 teachers representing 17 school districts participated.

BAESI Philosophy: A Program for and by Teachers

The Bay Area Earth Science Institute promotes science for all students through a community-based earth science training program that encourages and develops the diverse skills Bay Area teachers have to offer. Teachers have been active in the planning and implementation of the BAESI program since the concept was first developed. The specific goals of BAESI are to:

- improve the basic understanding and teaching skills of K-12 science teachers in the San Francisco Bay area with respect to earth science concepts and activities,
- provide a model program for teacher training in the earth sciences that can be adapted to virtually any area in the country, and
- compile the best of 'acher-designed and classroom-tested earth science activities for a resource book to be used by any teacher seeking quality, hands-on earth science activities.

The BAESI Model

The Bay Area Earth Science Institute takes a three-fold approach to improving the earth science skills of teachers:

- Each year a new group of about 35 teachers is selected to participate in a month-long, five-day per week summer workshop held at San Jose State University (SJSU).
- Workshop participants are brought together again during the academic year for workshops in the spring and fall.
- A year-round support program includes newsletters, membership in steering committee and resource book planning groups, and access to a resource center from which maps, rocks, minerals, compasses and books can be borrowed.

On-going planning and administration is the responsibility of two co-directors (faculty in the Department of Geology at SJSU) and a steering committee made up of 15-20 Bay Area teachers, school administrators, and representatives from a supporting consortium of government, academic and corporate agencies.

Fostering Educational Partnerships

The Bay Area Earth Science Institute is a working model of cooperation among academic, government and corporate agencies with a common interest in improving science education.

As a partner, BAESI helps other agencies to plan science education activities, assists with teacher-led field trips, provides teaching materials, facilitates teacher participation in professional meetings, and assists with integrating earth science into the curricula of area schools.

Teacher partners provide planning and feedback, contribute to the BAESI resource book, serve as instructors in the summer workshop, and help with recruitment. Government, academic, and corporate agencies provide cost-share funds and donation of materials.[1] Professional scientists work closely with teachers by serving as guest lecturers and field trip leaders.

The Nuts and Bolts of BAESI's Programs

Participant Selection

BAESI's first priority is to select and train teachers from schools with high (greater than 50 percent) minority enrollments. The ethnic diversity of the Bay Area is well suited to reach students who are traditionally under-represented in the sciences.

Teacher participants are not required to have pre-existing expertise in the earth sciences, but must demonstrate an enthusiasm to learn and a willingness to work hard and share ideas with colleagues. Teachers are encouraged to apply as teams of two to four from the same district or school. Part of the application process is to obtain approval for participation in the program from principals and district supervisors and a pledge of release time to allow attendance at required follow-up activities.

The Summer Workshop

In 1990 and 1991, 66 teachers completed the BAESI summer workshop. Participants were elementary, middle, and high school teachers recruited from schools in the Bay Area from San Francisco to San Jose. There were also participants from as far away as Bakersfield and Stockton. BAESI has also received applications from teachers in Pennsylvania, Nevada and North Carolina. Participants receive a stipend, as many as four units of continuing education credit, and free classroom materials. In return, they work in teams to develop hands-on activities that are suitable for their own classrooms. These activities are compiled at the end of each summer workshop and distributed to participants. At the end of the third summer workshop, the best of the earth science activities developed by BAESI teachers will be compiled in a teacher-tested resource book.

Workshop participants are also required to submit individual or team plans for projects to be implemented during the following academic year. Follow-up projects include inservice presentations at their schools, presentations at local, state or national meetings, planning of field trips and serving as guest lecturers in each other's classrooms.

During the four-week summer workshop, regionally significant earth science topics are gradually developed from general concepts to applications specific to the Bay Area. At least one day per week is devoted to field trips. Workshop topics include earthquakes and plate tectonics, water and weather, mineral and energy resources and Earth history. In 1992, the third year of the Institute, a new component on space science and astronomy will be added. BAESI alumni are invited to return and participate in new aspects of the program. Specific summer workshop topics, guest speakers, and field trips are varied from year to year to encourage the continued participation of BAESI teachers from previous workshops.

The Year-Round Program

All BAESI teachers are required to attend two-day follow-up workshops each fall and spring. These meetings are a combination of additional earth science training and planning and evaluation sessions. As examples, follow-up workshops have focused on coastal processes at Pt. Reyes National Seashore and modeling of local field trips through study of the geology of Alum Rock Park in San Jose. Follow-up evaluation focuses on ideas and activities actually used in the classroom and their levels of success. Teachers also provide input on planning for future summer institutes and for advertising the program.

About a dozen teachers remain active as members of the steering committee and resource book group. These teachers provide a long-term perspective and continuing support for the Institute to maintain its momentum.

A newsletter is distributed three or four times a year to inform BAESI alumni and supporting partners of new directions in the program and of upcoming lectures and field trips of interest to earth science educators.

Program Evaluation

Perhaps the most challenging aspect of organizing a teacher-training workshop is deciding how to assess its strengths and weaknesses. The long-term impact of BAESI can only be evaluated by tracking participants over time to determine how participation in the program affects their classroom teaching. An extensive evaluation form is handed out on the last day of each summer workshop to determine participant perceptions of the workshop's high and low points. One teacher wrote: "Over the past 26 years of my professional life I have participated in six National Science Foundation workshops in various science disciplines. None of these past workshops have compared with the preparation and breadth of this four-week earth science workshop." Another participant commented "I can say without a doubt that the BAESI workshop has helped me become a better teacher. My students will benefit by having a more knowledgeable teacher, more interesting activities, and most importantly a more energized instructor."

The most valuable form of assessment for the summer workshop is the daily distribution of an evaluation form designed by Wendell Potter and Phelan Fretz of the University of California at Davis. The form consists of four questions: " What went well and why?"; "What needs improvement and why?"; "What do you want to see changed?"; and "Troublesome concepts or aspects of the teaching approach?". The direction of the workshop and its ability to meet the needs of its members are greatly enhanced by this immediate feedback.

Impact of the Program

The most effective measure of BAESI's impact may lie in the activities of its teacher participants and university directors. Two BAESI teachers gave presentations about their earth science teaching strategies at the 1991 Cordilleran Section meeting of the Geological Society of America Meeting in San Francisco. Four BAESI alumni have enrolled in the Masters in Natural Science degree program at San Jose State University; two are enrolled in advanced geology courses. Through the efforts of its co-directors and steering committee, the Institute is a participant in a variety of local and regional earth science education projects. BAESI is a member of the South Bay Natural Resources Education Consortium, an alliance of diverse local agencies including the Santa Clara Valley Water District, Pacific Gas and Electric Company, and the San Francisco Bay National Wildlife Refuge, which assists the Santa Clara County Office of Education in providing science resources and teaching strategies to local teachers. The Institute has aided Independence High School in San Jose, one of the 100 schools in the California SS&C project, with incorporating earth science into its restructured curriculum. BAESI has been cited as a model in a teacher-training proposal submitted to NSF from California State University at Northridge.

Future Directions

The history of science education is littered with examples of good programs that fizzled out after initial successes due to lack of funding. BAESI co-directors and steering committee members continue aggressive grant-writing efforts to assure the continuation of BAESI's programs after initial NSF funding is expended. The Bay Area Earth Science Institute will continue to evolve to best meet the needs of science teachers of the Bay Area. Future workshops will incorporate oceanography, meteorology, field mapping techniques, and advanced topics in the earth sciences. Plans are underway to increase the scope of the Institute's impact by establishing a similar program in Southern California. Pending funding, San Jose State University and BAESI will become a regional center for the educational partnership programs of the Geological Society of America.

End Note

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Teacher Education in Biology: A Teacher Enhancement Program That Works!

Crellin Pauling

San Francisco State University offers an interdisciplinary program that provides secondary school biology teachers with (1) a laboratory-based workshop at Enrichment Centers housed on university campuses, (2) a symposium on the ethical and social issues of molecular biology and biotechnology, (3) renewal meetings for follow-up support focussed on the evaluation of supplementary curricular materials for regular, honors, and AP biology classrooms, and (4) outreach support via Helix I and scientist-educator partnerships.

Background

Molecular biology has become one of biology's major themes; molecular biologists are exploring new horizons not dreamed of a decade ago. Although molecular biology had its origins in the elucidation of the mechanisms of heredity, it now has applications throughout the spectrum of disciplines that comprise biology. Molecular approaches are used in evolutionary biology, ecology, systematic biology, neurobiology and behavior, as well as in genetics and cell biology. Accompanying these new insights in molecular biology is an explosion of applications of biotechnology in such diverse areas as health care, pharmaceuticals, agriculture, and forensics, to name a few. This avalanche of biotechnology results in scientific and ethical uncertainties in medicine, agriculture, and law, while at the same time, forecasts far reaching social and economic benefits for the nation and the world.

These new scientific and ethical questions are forcing a re-evaluation of public policy in science and technology education. The need for science literacy is self-evident, but the need for understanding of the fundamentals of the biotechnology revolution is increasing. Juries will hear cases in which molecular forensic techniques are used for identification. Local governments and zoning commissions will regulate industries that use biotechnology. Business interests will make investment decisions. Unfortunately, high school classrooms generally have not maintained currency with these expanding horizons in science and with their impacts on our society.

The California State Department of Education (SDE) has mandated that major emphasis be placed on the ethical concerns and technological applications when biology teachers present DNA and related topics of molecular biology. The *Science Framework for California Public Schools* (1990) is the guide to the high school biology curriculum in California. The Science Framework states:

> For a participating democracy to succeed and flourish, an informed public in which citizens make knowledgeable decisions on technological issues is necessary. Students and teachers must have both a firm understanding of the sciences and an ethical framework for applying these ideas in a technological society. Failure to emphasize both science and ethics in the biology curriculum means, in the final analysis, failure to fulfill teaching's most important function: to prepare citizens capable of informed decision making in both the personal and public arenas. (p. 136)

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Students' understanding of the sciences and technology and their related ethical issues is also emphasized as an imp tant component of scientific literacy in *Science for All Americans*, the Phase I report of the American Association for the Advancement of Science's Project 2061.

In *Fulfilling the Promise: Biology Education in the Nation's Schools*, the Committee on High-School Biology Education convened by the National Research Council found:

> The growth of scientific knowledge during the twentieth century has been without precedent in human history; science and technology permeate our culture. Some degree of familiarity with how scientific knowledge is obtained, with certainty and uncertainty, with the living and nonliving world, with basic mathematical ideas (numeracy), with how an understanding of nature and of the human body contributes to healthy lives and a safer world–in short, the basic foundation that is referred to as scientific literacy–has become an educational necessity. (p. 5)

The National Science Teachers Association (NSTA) position paper, *Science-Technology-Society: Science Education for the 1980's*, states:

> The high school science curriculum should enable students to further develop their scientific and technological literacy. Courses incorporating well-designed laboratory and field work help to meet this need....The courses should provide students with opportunities to develop skills in identifying science-based societal problems and in making decisions about their resolution. (Bybee, 1985)

We established the Teacher Education in Biology (TEB) program at San Francisco State University (SFSU) in 1987 to provide interdisciplinary education for middle and high school biology teachers in (1) laboratory-based methods designed for teaching about DNA, gene-splicing, etc., and (2) the ethical concerns and technological applications on the frontiers of biology. The TEB program was designed to provide program participants with the pedagogical methodology needed for classroom implementation of this material as well. This has been accomplished through a series of workshops, symposia, and renewal follow-up sessions. The TEB program has received strong educational, industrial, scientific, and governmental support and cooperation throughout California, and, we believe, serves as a national model for interdisciplinary education in science and ethics.

In summary, the interdisciplinary approach to the science and ethics of molecular biology taken by this program leads teachers to a clearer understanding of:

- the function of the genetic material;
- the fundamental recombinant DNA laboratory techniques;
- the social framework necessary for translating knowledge of today's biology into personal decisions and public policy;
- current and future applications of recombinant-DNA technology in medicine, agriculture, forensics, and industry; and
- the processes for ethical discussion and analysis of science and technology topics within the science classroom.

Development of TEB

In summer, 1987, we presented a one-week pilot laboratory-based workshop in molecular biology at SFSU for 24 teachers. Based on the success of the pilot workshop, we obtained funding to continue and expand the program in 1988. We presented a four-day preworkshop for 32 program participants that was designed to bring the lesser-prepared teachers up to par. We offered three two-week laboratory-based workshops for 24 program participants each at SFSU, California State University, Sacramento (CSUS), and University of California, Santa Cruz (UCSC), that were followed by a three-day symposium at UCSC on Science and Societal Issues in Recombinant DNA for all program participants.

Subsequently we have presented workshops at San Francisco State University (89-92), California State University, Sacramento (89, 91), University of California, Santa Cruz (89-91), California State University, Fresno (90-92), San Diego State University (90-91), California State University, Los Angeles (92), and California State University, Northridge (92). Again, the workshops have been followed by the three-day symposium for all participants. At the conclusion of summer, 1992, over

500 California middle and high school science teachers have participated in the TEB program.

There are five major program components:

- a two week laboratory workshop in basic recombinant DNA techniques and strategies for classroom implementation;
- a three day symposium on societal and ethical issues of recombinant DNA;
- instructional partnership and *Helix I* outreach services;
- two one-day renewal follow-up sessions; and
- educator-scientist partnerships.

The TEB program has worked with participating teachers in developing funding strategies with their districts and with outside funding sources. To date, teachers affiliated with this program have collectively acquired more than $200,000 in support intended for implementation of this material in their classrooms. The majority of program participants have been high school teachers; however middle school science teachers became an integral part of the program in its fourth and fifth years. Participating teachers have been derived from both urban and rural districts, with teaching assignments ranging from AP Biology to general science.

We believe that there are several components to the TEB that distinguish it from other teacher-enhancement programs. These include:

- use of two university faculty and two lead teachers to provide instruction during the workshops;
- the linkage between the basic science and the societal-ethical issues through the symposium; and
- implementation support via the follow-up sessions, *Helix I* outreach and the educator-scientist partnerships.

Furthermore, we believe that these unique components have played a major role in the high degree of success that has been achieved by the TEB thus far.

Current Design of the Teacher Education in Biology Program Workshops

The first component of the TEB is a two-week laboratory workshop, conducted on a university campus, in basic recombinant DNA techniques and in approaches for classroom implementation. The participants receive an intensive short course in the fundamentals of genetics and molecular biology, including extensive hands-on experience in basic techniques. They learn to isolate and purify DNA, hydrolyze samples with restriction endonucleases, perform gel electrophoresis, stain and photograph the gels, perform blots, anneal and ligate samples, and perform transformation of competent bacterial cells. In addition, they get experience in trouble-shooting lab protocols. The workshops also assist in the development of lesson plans, thus ensuring that the participants can implement the material in their classrooms.

The workshop is designed around the material presented in *DNA Science* (Micklos & Fryer,1990). Participants are provided with a copy of *DNA Science* and a three-ring curriculum notebook containing a workshop schedule, supplementary support material, and innovative laboratory exercises. In addition, at the conclusion of the workshop participants are provided with a basic kit of expendable laboratory supplies and an electrophoresis kit, so that they are able to teach the exercises in their own classrooms.

Instruction is provided by a team consisting of two university faculty, two lead teachers, and a laboratory support technician. The university faculty are selected on the basis of their expertise in genetics, molecular biology, and recombinant DNA techniques. They are responsible for the presentation of the didactic lecture material and for the selection, design and supervision of the laboratory exercises. The lead teachers are inservice teachers who have participated in the TEB program in a previous year and who have successfully implemented the material covered by the program in their own classrooms. The lead teachers are a critical component of the workshops in that they work closely with the university faculty in presenting the laboratory component of the workshops and are responsible for the components concerning implementation and lesson plan development. We believe that the employment of former program participants as lead teachers has played a significant role in the success of the TEB, because they serve as positive role models for the program participants.

The laboratory support technician prepares bacterial culture media, solutions and buffers, cultures, DNA and enzyme preparations, and provides other support as needed. In addition, the laboratory support technician often works with the workshop instructors to provide additional technical details for the program participants.

At the conclusion of the workshop program participants receive a Professional Development Certificate and are offered the opportunity to register for academic credit through the Division of Extended Education at San Francisco State University.

Symposium on Societal and Ethical Issues

The second component is the three-day symposium on societal and ethical issues of recombinant DNA, held on a university campus and open to any California science teacher who has completed a basic course in recombinant DNA. The symposium opens with a keynote address presented by a nationally known figure. In 1990 the keynote speaker was Clifford Grobstein, Professor of Biology at University of California, San Diego; in 1991 Paul R. Billings, MD, PhD, California Pacific Medical Center, presented the keynote address entitled *Social Concerns in the Genetic Age*. Teachers then hear additional presentations and discuss these issues with nationally recognized scientists, educators, policy makers, ethicists, and philosophers. Following these discussions, the teachers, speakers, and program staff work in small groups to develop simulations, case studies, short vignettes, and other strategies for implementing these challenging science, technology, and society issues in the classroom.

Instructional Partnership/
***Helix I* Outreach**

The third component is a team-teaching instructional partnership during the academic year. *Helix I*, a mobile molecular biology laboratory funded by Genentech, Inc., is equipped with all the needed materials and supplies. *Helix I* visits the classrooms of selected teachers to help with the set-up and instruction of a two to four week unit on molecular biology. A critical component of the *Helix I* program is that an instructional expert from TEB accompanies the outreach vehicle and team teaches with the classroom instructor. This on-site partnership assists teachers in classroom implementation during the first year after the workshop. *Helix I* and program staff also participate in school and district inservice programs. We have found this component critical for the actual classroom implementation, both by providing support for the teachers and by reinforcing the teachers' understanding of molecular biology and biotechnology.

It is without question that the *Helix* outreach program has been a success in accelerating and supporting classroom implementation of TEB's instructional materials into the biology and chemistry curricula. One early concern with the *Helix* program was that this form of assistance would be used as a crutch by the teacher and not lead to lasting change. For the majority of teachers this has not proven to be the case. Instead, we conclude that the *Helix* program has stimulated teachers to arrange for inservice sessions for themselves and their colleagues, to prepare grant proposals, and to request support from industry and universities, in order to continue providing for their students what they observed could happen during the *Helix* visit.

Renewal Follow-Up Sessions

The fourth component is two one-day renewal follow-up sessions, held on Saturdays during the fall and spring terms following the teachers' participation in the workshops. The renewal sessions bring the previous summer's participants together to reinforce the information covered in the program, to share information concerning successful strategies for lesson development, fund-raising, and to address other issues surrounding successful implementation.

For the participants in summer, 1990, one follow-up session was held at the regional NSTA meeting in Long Beach, California. Participants heard a presentation on "Quantitative PCR of HIV-Infected Patients," heard a summary report on evaluation and assessment of the current year's program, and received their electrophoresis kits. The second follow-up was scheduled as regional meetings, with one at SFSU (serving both SFSU and UCSC participants), one at CSUF, and one at SDSU. They had a common agenda that included an introduction to some new and innovative lab exercises and a workshop discussion of the molecular definition of a gene.

Educator-Scientist Partnerships

The fifth component is an educator-scientist partnership program in which participating teachers are provided partner scientists and technicians in the biotechnology industry or research faculty from universities. These partnerships develop slowly and personally between the two individuals and have, in many cases, expanded into long-lasting relationships that bring both personnel and material into the classroom. It has also been the beginning for a company to become more invested in their local schools. Many classroom visits by scientists, field trips to research laboratories, and a considerable amount of technical assistance and equipment/supplies donations have occurred as consequences of these partnerships. The teacher-scientist partnerships and the staffed *Helix I* mobile laboratory have substantially contributed to teachers' efforts to change curricula and implement new laboratory-based materials. Because of this program some scientists are becoming science teachers. In collaboration with the Lawrence Hall of Science CELLS Program (California Education Linkages in the Life Sciences), six scientist partners spent a full day at the 1990 UCSC TEB workshop in the lab with the teachers and afterwards in discussion about partnerships. These scientist-teacher connections have been maintained, and the scientists have participated in classroom events over the 90-91 school year. This was a very successful partnership, and this model will be expanded in the coming years' program.

San Mateo County Biotechnology/Education Partnership

The ultimate goal of the TEB program is to bring about a permanent change in the way that biology, and, in fact, science is taught in the secondary school curriculum, consistent with the *Science Framework*. It is our view that the biology curriculum must be current, must be inquiry-based, and must relate to the society in which we all live. Furthermore, this revised curriculum must be self-supporting and not dependent upon continuing support from TEB staff. As a model expansion of the *Helix I* program, the San Mateo County Biotechnology/Education Partnership (SMCBEP) has been established as a partnership of several TEB participating teachers, the San Mateo County Office of Education, two San Mateo County community colleges, and Genentech, Inc. Funding provided by Genentech has provided an instructional package that is available to all public high school teachers in the county, with expendable supplies refurbished by the community colleges. Described by Black, Liu and Ogren later in this issue, the SMCBEP represents exactly what the TEB program hopes to achieve.

Summary and Conclusions

The TEB has successfully presented two-week laboratory-based workshops on molecular biology and biotechnology to over 500 California teachers. In addition, the participants have attended a symposium addressing the ethical and societal issues of recombinant DNA and biotechnology, and many have been served with outreach support from the *Helix I* program and the scientist-educator partnerships.

Both objective and subjective measures lead to the conclusion that this program is extraordinarily successful. Our evaluation data show that the participants do learn the material and show improved attitudes towards teaching the material. Testimonials from both the participants and their students show that the program has revitalized the teachers and sparked real interest among the students. The program effectively links the basic science with the equally important societal and ethical issues surrounding the science. In short, because of this TEB program California is the leader in molecular biology/biotechnology education in secondary schools in the nation.

Acknowledgments

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San Mateo County Biotechnology/Education Partnership

Sue Black
Kathy Liu
Stan Ogren

"I feel pretty important and professional using all this high-tech equipment. It's a neat experience!"
"I feel like a real scientist! "
"The part I like the best was finding out for myself. . ."
"I was pretty scared doing my first lab, but when I discovered that my DNA was cut, my confidence built up."

These are comments by students who have just spliced together antibiotic resistant genes, put them into prepared bacteria and grown the bacteria in the presence of the antibiotics. During the past two years, these students and more than 4000 of their peers in San Mateo County have done a series of high tech recombinant-DNA experiments. This technology is similar to that used by scientists in university and industrial research labs.

In the first week of labs, students learn to use equipment not usually available to high school students. Students become adept in the use of micropipets, which measure amounts as small as one microliter (1,000 µl = 1 mL; approximately 5 mL = 1 teaspoonful) so that later they will be able to accurately aliquot the very small amounts of DNA, enzymes, and needed reagents. They master power supplies and gel boxes so they can use a process called gel electrophoresis to separate DNA fragments by length. They learn sterile techniques for handling DNA, enzymes, and bacteria so their bacteria can grow uninhibited by contaminants. (Safety is emphasized despite the fact that the bacteria used will not easily grow outside the culture medium provided.)

In the second and third weeks, students participate is a series of labs (adapted from Miklos & Freyer, 1988) during which they:

- use enzymes to cut two different bacterial chromosomes (plasmids) into pieces;
- use gel electrophoresis to check that the DNA was actually cut;
- use another enzyme to fasten pieces of DNA to each other;
- treat bacterial cells so that they will take in DNA (make competent cells);
- introduce DNA they have recombined into receptive (competent) bacteria; and
- test bacteria for the expression of recombinant DNA by spreading the cells on nutrient agar mixed with one antibiotic, two antibiotics, or with no antibiotic.

In other experiments supported by this project, students isolate and spool DNA, simulate forensic DNA fingerprinting, and learn bacterial plating techniques.

> Students react to the labs . . .
>
> with awe: *"each procedure should be savored by the students,"*
>
> with frustration: *"If only we could have had more time," "We went too fast,"*
>
> and with understanding: *"There is a lot riding on one microliter," and "It is interesting to be learning about the future in the present."*

Sue Black, Aragon High School,
Kathy Liu, Westmoor High School, and
Stan Ogren, Menlo-Atherton High School,
are science teachers in San Mateo County.

A Partnership That Delivers

All of this is happening just south of San Francisco, in San Mateo County, California where we have created a partnership that delivers equipment and supplies for the above mentioned experiments to high school classrooms throughout the county. Precision micropipets, gel boxes, power supplies, prepared reagents, sterile media, enzymes, plasmid DNA, and other sophisticated equipment and reagents are delivered directly to high schools, ready to use. Detailed laboratory protocols, student worksheets and an extensive teacher resource file come with the kit.

Our students are beneficiaries of a partnership which involves an industry (Genentech), a community college (Skyline College), a county office of education (San Mateo C.O.E.), teachers from three high school districts (the authors of this article), and a university consultant (Lane Conn, Manager of the Teacher Education in Biology program (TEB) at San Francisco State University).

How It All Began

The idea to establish a cooperative, county-wide program was conceived during a three day symposium in the summer of 1989 sponsored by San Francisco State University (SFSU), the National Science Foundation (NSF) and the California State Department of Education. As is usual at gatherings of teachers, there was a lot of "shop talk" and sharing–sharing of excitement and sharing of frustrations. The three of us had taken the exciting TEB workshop in the techniques of molecular biology and wanted our students to share our excitement. Individual department budgets could not afford the necessary equipment, and our schools do not have autoclaves with which to sterilize the reagents and supplies required for such a program. We hypothesized that a county-wide cooperative effort would be a more efficient use of resources and would have a better chance of being funded. We three teachers decided to work together to secure funding for the equipment, supplies, and support we needed to implement recombinant-DNA experiments into our classrooms.

The first step in making our dream a reality was forming the San Mateo County Biotechnology Education Steering Committee. If we were to be a county-wide project, we needed to involve the County Office of Education. Gary Nakagiri, Math/Science Coordinator for San Mateo County, was supportive of the idea and joined the committee as the county representative. Once we applied for grant money, the county would become the fiscal agent for our project. Lane Conn, Project Manager of the TEB, joined our steering committee as a consultant.

We needed laboratory protocols and a list of equipment, materials, and supplies to support them. Using SFSU's TEB out-reach program as a model, we established a wish list of equipment, materials and supplies.

Four more major hurdles needed to be overcome. We needed:

- funds;
- a refurbishing center where someone would prepare solutions, replenish the kit between schools, and autoclave materials;
- a way of getting the kits from one school, to the refurbishing center, and back to another school; and
- scientific expertise.

The Audio-Visual Department of the County Office of Education agreed to transport our equipment in a van usually used for delivering films to county schools. (While we refer to "the kit" as a singular unit, in reality the kit consists of 26 crates of material.)

Two Genentech scientists joined our steering committee. Drs. Cori Gorman and Paul Godowsky provided considerable support to the project when it was in its infancy. They provided technical advice both over the phone and in the classroom. Dr. Gorman is now co-chair of our Bioethics Subcommittee. She continues to assist us with the procurement of competent cells and other biological materials, refinement and trouble shooting of laboratory procedures, and curriculum development.

Dr. Christine Case, Biology Professor from Skyline College, also joined the Steering Committee. She brought with her scientific expertise and the participation of Skyline College. Skyline agreed to be the refurbishing center for the kit. Our project would pay a technician to prepare reagents and media, sterilize equipment and reagents, and properly dispose of biological waste generated at school sites. Dr. Case established protocols for safely handling the materials in the kit and serves as an advisor on curriculum development.

We were anxious to get started. If we could get funding in time, we would run a three-school pilot program to test equipment and procedures during March, April and May. The kit would remain at each school for approximately three weeks. Between schools, it would spend a week at Skyline.

The Steering Committee made a presentation to the Board of Directors of the Genentech Foundation for Biomedical Research. Our proposal was funded, and we were on our way. Prior planning made it possible for the program to move forward immediately upon receipt of the check. Equipment bids were finalized. Equipment and supplies were ordered. Our kit was assembled. A reception featuring student-led biotechnology experiments was held at the County Office of Education to introduce the program to county and district administrators, school principals and others invited guests.

Table 1

Overview of Biotechnology Laboratory Experiments

Techniques Labs

A. **Manipulating small volumes**
Skill: Select and use the correct micropipet to accurately measure volumes from 2 µL- 1000 µL.
Concept: Very small amounts of DNA, enzymes and buffers are used in these labs.

B. **Electrophoresis**
Skill: Safely set up and use gel box and power supply.
Concept: Discover the function of each component used in electrophoresis.

C. **Casting and loading an agarose gel**
Skill: Practice casting, loading, and running an agarose gel.
Concept: Electric current running through gel separates compounds put into agarose wells.

D. **Making cells competent**
Skill: Make *E. coli* cells competent to undergo transformation with exogenous DNA.
Concept: The cell walls of *E. coli* must be treated in order for the cells to take up DNA from their surroundings.

E. **Plating bacteria**
Skill: Use sterile technique to streak two kinds of nutrient agar (with and without an antibiotic) with *E. coli*.
Concept: Sterile technique is used to avoid bacterial contamination. Bacteria, like all living things, have different genotypes and different phenotypes.

Introductory Labs

101. **Precipitating and spooling DNA**
Skill: Precipitate and spool DNA.
Concept: DNA is real. In large amounts, it can be seen and touched.

102. **pAmp transformation**
Skill: Introduce DNA containing a gene for ampicillin resistance into *E. coli*.
Concept: Introduced DNA can change the properties of bacterial (and other) cells.

Recombinant DNA Labs

201. **Restriction enzyme digestion**
Skill: Perform side-by-side restriction digests of plasmids containing two different antibiotic resistant genes.
Concept: Restriction enzymes cut DNA at locations determined by the sequence of DNA bases

202. **Gel electrophoresis**
Skill: Use gel electrophoresis to determine whether DNA was cut during restriction digest.
Concept: Gel electrophoresis separates DNA fragments by size.

203. **Staining and photographing gels**
Skill: Stain and photograph DNA in agarose gels.
Concept: DNA can be made visible by staining. Photographs preserve results for study.

204. **Ligation**
Skill: Ligate DNA fragments obtained in Lab 201 to produce recombinant DNA.
Concept: Ligation enzymes catalyze the connection of DNA fragments. Some of the ligated DNA contains both of the antibiotic resistant genes (recombinant DNA).

205. **Transformation**
Skill: Introduce ligated DNA into receptive *E. coli* cells.
Concept: Once inside bacteria, ligated DNA "transforms" the bacterial cells so that they express new traits (in this case, antibiotic resistance).

206. **Expression**
Skill: Select for cells resistant to antibiotic resistant genes by plating them onto agar containing antibiotics.
Concept: Growth of colonies on agar containing antibiotics shows that cells are expressing their new genes.

Advanced Labs

301. **Spooling DNA from thymus glands**
Skill: Isolate, precipitate and spool DNA from calf thymus, "sweetbreads."
Concept: DNA can be isolated from cells. After isolation and precipitation, it can be seen and touched.

302. **Effects of DNA methylation on restriction enzyme digestion**
Skill: Use gel electrophoresis to determine whether DNA was cut during restriction digestion.
Concept: Methylation of DNA protects it from digestion.

303. **DNA fingerprinting**
Skill: Use gel electrophoresis to visualize pieces of DNA.
Concept: Restriction enzymes produce unique fragment patterns of DNA from different sources.

Spring 1990–The Birth

The kit, temporarily dubbed "Science 2000," was delivered to Aragon High School. Just seven months after the idea of a county-wide biotech program was conceived, 165 biology students were splicing DNA. By the beginning of June, more than 700 students in 24 sections of life science, biology and advanced placement biology classes at Aragon, Menlo-Atherton, and Westmoor High Schools had participated in the pilot project. Parents, administrators, and school board members had attended three very successful open houses. The San Mateo County Biotechnology/Education Project was on its way.

Summer 1990–A Time For Consolidation, Revision, and Planning Ahead

At an intense, one-week workshop, we reviewed program procedures, equipment and supplies. The biggest complaint from students and teachers alike was that the time was too short. Schools needed more time with the kit. Another complaint was that because Skyline did not need to refurbish every crate, moving all twenty six crates into and out of storage at Skyline was inappropriate. The crates were reorganized to consolidate the materials that needed to be replenished. Procedures were revised, sending only six of the twenty-six crates to Skyline and the rest on to the next school. This effectively gave each school an extra week with the kit.

In additon to making kit changes, we reviewed applications from potential participants, revised laboratory protocols and wrote student worksheets. Some of the labs proved extremely difficult to finish in 50 minute class periods. In some cases, changes were made in student and teacher instructions to show where the lab could be safely stopped and continued the next day. For other labs, steps were rewritten to take less class time.

1990-1991–Full Implementation

By September, the labs and the kit were ready for the school year. During the 1990-91 school year, the kit was in use continuously from the middle of September until the end of May. Over 1800 students of 15 teachers at eight high schools used our kit to do recombinant DNA experiments.

Summer of 1991 meant several new projects for the SMCEBP Steering Committee: the drafting of new laboratory protocols, the production of a floppy disk to simplify the dissemination of the materials we had developed, further revision of kit logistics, the creation of a Bioethics Subcommittee, and planning for a second kit. In terms of implementation, one of the greatest frustrations we as teachers had faced was lack of time. In spite of the fact that many of the required solutions are prepared and/or sterilized by Skyline College technicians, there is still a great deal of preparation that must be done at the school site. This preparation was particularly stressful when, due to time constraints, the labs had to be scheduled on three or four consecutive days. Students, too, were overwhelmed by such schedules. The addition of a second kit during the 1991-92 school year (purchased with a generous second-year grant from the Genentech Foundation for Biomedical Research) allowed the time at each school to be extended an extra week or more, thus reducing the stress of implementation on teachers and students alike.

The Future, Today

The addition of a second kit was just a first step in our expansion plans. As more teachers hear about and see this program in action, more want to participate. So far, we have not had to turn qualified participants away. Eventually, we would like to expand the program to include all county high schools with support for related experiments in general science, chemistry and physics as well as additional biology experiments. This will mean multiple sets of equipment, additional re-supply centers and a full time coordinator/mentor/teacher.

However, comments like these from our students show that educational partnerships like this one are worth the effort:

> "At first I thought that biology was just another class."
>
> "Letting us use the sophisticated equipment gives us the trust we deserve."
>
> "(These labs) allowed me to believe that science is more than just reading and memorizing."
>
> "It has made me notice that there are still things in the world to be found."

"I know that a lot of effort went into these labs, and I really appreciate it. Thank you."

Partnership Participants

Partnerships such as this one take time and commitment to make them work. Ours has been successful because of the dedicated cooperation and commitment of many people. Listed below are the people and foundations who have made our program work. We join the students in thanking each one of them.

San Mateo County Office of Education
Gary Nakagiri, Math/Science Coordinator, and LeRoy Finkel, Director, Media Services

Skyline College
Christine Case, Professor, and Patricia Carter, Laboratory Technician

Genentech, Inc.
Cori Gorman and Paul Godowsky, Scientists

San Francisco State University
Lane Conn, Program Manager, Teacher Education in Biology

Genentech Foundation for Biomedical Research

Peninsula Community Foundation

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San Francisco State University
School of Education *Review*
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The SOE *Review* is published every year by the Research and Development Center of the School of Education at San Francisco State University. It is designed to stimulate thinking about a variety of educational issues, and to foster the creation and exchange of ideas and research findings that will expand knowledge about the purposes, conditions, and effects of schooling.

The focus of the journal is on "best practice, supported by research, theory, or experience." Manuscripts are welcomed on a variety of topics, so long as they are related in some way to educational issues and concerns:

- conceptual pieces;
- empirical and other research investigations;
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- innovative teaching practices;
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- reviews of literature;
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All manuscripts submitted to the School of Education *Review* should conform to the *Publication Manual of the American Psychological Association*. Manuscripts are to be double-spaced, typewritten or (preferably) word-processed (using Microsoft Word for the Macintosh computer), and submitted in quadruplicate (an original and three copies), along with the disk on which the manuscript was typed. All manuscripts are blind reviewed by three reviewers, and then either accepted, accepted pending some revision, or rejected.

The original manuscript and three copies should be submitted to:

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Research and Development Center, Burk Hall 238

School of Education

San Francisco State University

San Francisco, CA 94132

Note to Authors

The *Publication Manual of the American Psychological Association* (most recent edition) has been adopted as the authority on format and style for the SOE *Review*. Authors should obtain a copy of the *Manual* and become familiar with its contents. The inside covers of the *Manual* contain a manuscript checklist which should be consulted before manuscripts are submitted for publication.

Authors are responsible for the quality of presentation of all aspects of their manuscripts. This includes correct spelling and punctuation, accuracy of all quotations, correct page numbers, complete and accurate references, and legible appearance. Since all manuscripts are blind reviewed, authors are responsible for preparing their manuscripts so as to conceal their identities.

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