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ABSTRACT

This document is composed of edited speeches from a meeting of directors of National Science Foundation (NSF) projects, NSF staff, and other selected invitees convened by the Division of Science Education Development and Research (SEDR). An introduction by Walter L. Gillespie, a copy of the three-day agenda, and 16 addresses are included. The titles and presenters of some of these addresses are "Integrated Research, Development, Dissemination and Practice in Science Education," Ralph W. Tyler with reactions by Robert Karplus and Ronald G. Havelock; "The Role of the National Diffusion Network in Spreading Educational Innovations," Lee E. Wickline; "The Interpretation of Research and Development in Science Education," Rustum Roy; "Projects that Integrate Science Education Research and Development: Benefits of Interactions and Costs of Missed Opportunities," Mary Budd Rowe; "What Science/Math Education Researchers Say to the Development Community," Diane McGuinnes; "New Horizons in Educational Development," Jack Lochhead; "Current Targets of Opportunity - What Science/Math Education Developers Say to the Research Community," Howard D. Mehlinger; "Education in Science and Technology for All Americans," Izaak Wirsrup; and "Relating Research and Development in Education," Susan F. Chipman. (PEB)

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The opinions, findings, conclusions or recommendations expressed in these presentations are those of the speakers and do not necessarily reflect the views of the National Science Foundation.

FOREWORD

The Division of Science Education Development and Research (SEDR) has supported a variety of research and development activities designed to strengthen the Nation's system of science education. Since its establishment in 1976 it has sought to increase both our understanding of and our techniques for improving education in science at all levels and for all age groups.

To that end, the Division has made funds available for research projects designed to generate new knowledge or to synthesize existing knowledge about the science education process, and development projects designed to produce, test, and disseminate innovative science instruction.

From February 5 through 7, 1981, SEDR held a meeting in Washington, D.C., of recent project directors, NSF staff, and other selected invitees. The bulk of this publication consists of the edited texts of the papers delivered by the invited speakers. Most of the speakers have been or currently are grantees of this Division, and the range of the topics is representative of the wide scope of the Division's activities.

INTRODUCTION

In Science Education, "research" and "development" sometimes tend to be thought of as inherently separate, like Kipling's East and West. The purpose of the 1981 Project Directors' Meeting was to encourage "the twain to meet."

Individual leaders in the two fields had already begun a process of rapprochement, and their initial results have been encouraging. It now is possible to begin to speak, as Dr. Tyler does in his keynote address which follows, of "integrated research, development, dissemination, and practice" in science education. Projects that successfully integrate the parts appear to enjoy significant advantages over those that do not. Even the most reluctant convert will be impressed by the benefits described by Drs. Roy, Signell, McDermott, Robinson, and Rowe in their discussion of "Projects that Integrate Science Education Research and Development: Benefits of Interactions and Costs of Missed Opportunities."

At the meeting itself, the development community listened attentively to what researchers had to say to them through Drs. McGuinness, Lochhead, and Carpenter; the research community was equally attentive to ideas presented by developers Mehlinger and Hooper. Dr. Lipson's description of the natural clusters existing within the science and mathematics research and development communities, the linkages that connect these two groups and the barriers that separate them, provides a helpful cognitive map of the entire area. It also identifies in a useful way the sticky points that must be dealt with before more effective and sustained interaction can take place betweem them.

Dr. Wirszup, in his discussion of the science and mathematics achievements of the educational systems of the Eastern Bloc as compared with the U.S., provides the imperative for fostering greater interaction between the fields, and Dr. Chipman closes the volume by providing heartening evidence that institutional infrastructures are beginning to develop so as to support constructive changes in this area.

Without being overly sanguine, I believe that the papers which follow provide a rational basis for hoping that future science and mathematics educational developers will increasingly frame their projects in the light shed by recent research, while researchers in these fields will find through the experiences of the Nation's educational developers a healthy anchor chain to reality.

The meeting reported herein not only raises some important questions regarding linkages; it even offers some timely answers.

Walter L. Gillespie
Acting Assistant Director
for Science and Engineering Education

AGENDA
SEDR PROJECT DIRECTORS MEETING

February 5-7, 1981 -- Shoreham Hotel, Washington, DC

Thursday, February 5

8:30 a.m.	Pre-Session I	Cognitive Processes Group Organizer: Erik D. McWilliams Program Manager, RISE
12:30 p.m.	Pre-Session II	Curriculum Development Software Exchange Organizer: Gregg Edwards Program Manager, DISE
7:30 p.m.	Plenary Session I	
	Moderator:	Joseph I. Lipson Division Director, SEDR
	Keynote Address:	Ralph W. Tyler Director Emeritus, Center for Advanced Study in the Behavioral Sciences "Integrated Research, Development, Dissemination, and Practice in Science Education"
	Responses:	Robert Karplus Associate Director, Lawrence Hall of Science, University of California, Berkeley Ronald Havelock Professor of Information Study American University
	Announcements:	Alexander J. Barton Program Director, DISE, and General Chairman of the Meeting

9:45 p.m. Concurrent Video Presentations I

A. John M. Jobe - Oklahoma State University, "An Actuary, What's That?" and "Mathematics in Space"

B. Donald R. Johnson - University of Wisconsin, "Video Systems for Teaching Meteorology"

C. Michael Fiasca - Portland State University, "Mt. St. Helens - Causes and Effects"

D. Merlyn J. Behr - Northern Illinois University, "Manipulative Aids in the Learning of Rational Numbers"

E. Robert G. Fuller - University of Nebraska, "The Takoma Narrows Bridge Collapse - Videodisc Education"

F. Susan Riemer-Sacks - Barnard College, "Hormonal Control and Ring Dove Behavior"

Concurrent Poster Presentations I

Friday, February 6

8:30 a.m. Plenary Session II

Moderator: Dr. Lipson

Lee Wickline
Director, National Diffusion Network

"The Role of the National Diffusion Network in Disseminating Educational Innovations of Proved Utility"

Address: Donald N. Langenberg
Deputy Director, National Science Foundation

Kenneth A. Klivington
Program Officer
The Alfred P. Sloan Foundation

"How the Sloan Foundation's Science Education Programs Are Created, Managed, and Monitored

10:30 a.m.	Plenary Session III	
	Panel Presentation:	"Projects That Integrate Science Education Research and Development: Benefits of Interactions and Costs of Missed Opportunities"
	Moderator:	Rustum Roy Director, Materials Research Laboratory, Pennsylvania State University
	Panelists:	Peter Signell Professor of Physics, Michigan State University
		Lillian C. McDermott Associate Professor of Physics University of Washington
		James T. Robinson Center for Educational Research and Evaluation, Biological Sciences Curriculum Study Company, Inc.
		Mary Budd Rowe Professor of Education, University of Florida
12:45 p.m.	Concurrent Poster Presentations II	
1:30 p.m.	Concurrent Video Presentations II (Repeat of Presentation I)	
2:30 p.m.	Plenary Session IV	
	Moderator:	Robert F. Watson Deputy Division Director, SEDR
	Panel Presentation:	"Current Targets of Opportunity" A. "What Science/Math Education Researchers Say to the Development Community"

Panelists: Diane McGuinness
Research Associate
Stanford University

John Lochhead
Director, Cognitive Development Project
Department of Physics and Astronomy
University of Massachusetts, Amherst

Thomas P. Carpenter
Associate Professor of Curriculum and Instruction
University of Wisconsin, Madison

B. "What Science/Math Education Developers Say to the Research Community"

Panelists: Howard D. Mehlinger
Director, Social Studies Development Center, Indiana University

Kristina Hooper
Assistant Professor of Psychology
University of California
Santa Cruz

4:00 p.m. Concurrent Poster-Presentation III

5:00 p.m. Concurrent Special Interest Sessions

A. Discussion with Drs. Tyler, Karplus, and Havelock

B. Discussion with Drs. Roy, Signell, McDermott, Robinson, and Rowe

C. Science Education in Informal Settings

Organizers: Rita W. Peterson
Program Director, RISE

Carl J. Naegele
Program Manager, DISE

D. Technology Applied to Mathematics Teaching

Organizer: Dorothy K. Deringer
Program Manager, DISE

E. Tasks Facing R &.D: Meeting the New Soviet Challenge in Science Education

Izaak Wirszup
Professor of Mathematics
University of Chicago

Saturday, February 7

8:30 a.m. Plenary Session V

Moderator: Dr. Rita W. Peterson

Dr. Watson

"Issues of Interest to SEDR Project Directors"

Dr. Lipson

"The Science/Math Research and Development Workers: How They Cluster, What Linkages Connect Them, What Barriers Separate Them"

9:45 a.m. Panel Presentation: "What Next? - Fostering Greater Interaction Between Science Education Research and Development"

Panelists: Dr. Wirszup
Susan Chipman
Assistant Director for Learning and Development, National Institute of Education

11:00 a.m. Concurrent Special Interest Groups - Closing sessions

F. SEDR Projects and the Media

Richard Muldoon
NSF Public Information Officer

N.B. The word "Development" as used throughout this program refers to that extended process that includes development per se, testing and evaluation, revision, dissemination (may involve a teacher training component), utilization, and eventual updating.

INTEGRATED RESEARCH, DEVELOPMENT, DISSEMINATION AND PRACTICE IN SCIENCE EDUCATION

Ralph W. Tyler
Director Emeritus
Center for Advanced Study in the Behavioral Sciences

Dr. Ralph W. Tyler needs no introduction to anyone in the educational community, thanks to his long record of dedication to the many facets of education. His curriculum vitae reads like a history of the development of modern education, with experience as a high school teacher in Pierre, South Dakota, to his present positions as Director Emeritus of the Center for Advanced Study in the Behavioral Sciences, Senior Consultant at Science Research Associates, Inc., and President of the System Development Foundation. Born in Chicago, Dr. Tyler took two of his degrees in Nebraska, received a Ph.D. from the University of Chicago, and served for ten years as the Chairman of the Department of Education there. Dr. Tyler continues to remain current on the Nation's problems connected with bringing education into the Computer Age; and his discernment of the key elements involved is the highlight of his speech.

I believe it is generally obvious that the potential contributions research and development activities can make to the improvement of educational practice are far from fully realized. Two major factors contribute to this large gap between the possible and the actual. There is no generally accepted comprehensive conception of the dynamics of the various parts that make up research, development, communications, and practice in American education; and these parts are not functionally integrated. They are not even loosely coupled.

Where People Learn About Science

Most commonly, discussions of science education focus on school and college courses. However, both children and adults acquire their notions about science from experiences in all sectors of their lives. The attitudes and beliefs of parents, friends, and other respected adults are influential. The mass media, particularly television, provide information or misinformation, stimulate or dampen interests, and affect attitudes. Libraries and museums are important teachers for some people. Schools and colleges have a major responsibility for stimulating and guiding the science learning of children and youth, but they provide only part of the learning experiences of most people, and in many cases only a minor part. In seeking to improve science education, the larger environment should be examined and potentials for development explored. Very little research and development has been focused on the learning outside of schools and colleges.

How Teachers View Research

Even though many research and development activities involve schools, classroom teachers generally do not expect to benefit directly from the results of research. This attitude arises from teachers' perceptions that their problems are of little interest to researchers and from disappointing experiences with methods, materials, and devices.

In our highly decentralized educational system, the teacher is most directly accountable to the local authorities and to parents. As professionals, teachers feel a sense of responsibility to meet the expectations of the professional group with which they identify, but the standards are those of colleagues, not of scientists or educational researchers. Parents and boards of education are more likely to judge teachers by the way discipline is handled and by comparative scores on standard tests than by the quality of science teaching.

The importance teachers attach to student discipline should not be overlooked in designing learning systems. In most classrooms, the teacher is responsible for the instruction of one or more groups of 25-30 active students. The management of a class to focus attention on the sciences and to ensure that every student is actively involved is a matter of great concern to almost all teachers. This problem has been overlooked by many developers of methods, materials, and devices for science education.

Another factor which has helped to produce in teachers a skeptical or resistant attitude toward advice and recommendations from outside the local school group has been the continuing pressure from special interest groups. Some of these special interests are widely known, including anti-evolution, air-age education, physical fitness, drug and alcohol prevention, and school prayer. Many others are not so well known. Some of the groups are well intentioned, but the course of study cannot have the necessary cumulative effect if new pieces are being forced into it without a careful reappraisal of the whole. Because teachers recognize the dangers of responding to outside pressures asking them to tinker with the curriculum, many have developed an attitude of skepticism and rejection of all proposals from external groups. Unless they perceive the new ideas or materials as useful, they have little interest in trying to apply the ideas or use the materials.

The individual teacher usually welcomes assistance with specific problems, but not with problems that may exist elsewhere. Unfortunately, because research seeks universal explanations for puzzling phenomena, many educational researchers and developers have considered educational problems in general terms. For example, in the 1960s, programmed materials were developed for use in both elementary and secondary schools on the assumption that a common problem was the lack of carefully sequenced instructional materials. Several centers were established, some supported by public funds and others by educational publishers, to produce instructional materials systematically designed to furnish step-by-step guidance of student learning. Later, when these programs were evaluated and the results compared to the learning of students who used the traditional type of textbooks and supplementary materials, it was found that only a minor fraction of the students learned more when using programmed materials. Most of these were the so-called "slow learners." The majority of the students were not appreciably aided by the careful step-by-step sequencing. In fact, some of the more rapid learners appeared to do less well with programmed materials than with additional instructional materials. One can conclude that there are students who benefit by the use of programmed materials but the need for this detailed sequencing is not universal. Apparently, when particular cases of students having difficulty in working out a learning sequence were observed, it was tacitly assumed that this was a universal problem.

Another illustration of this assumption of universality is evident today. Public concern has been aroused throughout the nation over the illiteracy of some high school students. The cry of "Back to Basics!" has focused the attention of many schools on the teaching of literacy. Actually, the National Assessment of Educational Progress shows that more than 80 percent of American 17-year-olds can read and comprehend common material. Those who have not learned to read are largely from homes where the parents have had little or no education. The problem of illiteracy is an important one for some schools and some students, but it is not a universal problem. The public clamor for attention to "the Basics" has resulted in many places in an obsessive preoccupation with drill and practice on reading and arithmetic and a neglect of other important areas of instruction such as science, social studies, literature, art, and music.

The research and development community has often failed to understand the concerns of teachers and has attributed the lack of attention to research findings and new learning systems to a lack of interest in improving education or to the bureaucratic rigidity of the school system. Although some teacher resistance may be due to these factors, most of the failures to apply research are due to lack of mutual appreciation of problems.

The Function of Research in Education

Research in all fields is an activity seeking to understand certain phenomena, that is, to explain each phenomenon in terms of general concepts and principles that are applicable to many particular examples of it. Greater understanding of a phenomenon does not always result in greater control of it, but it furnishes a basis for thinking more clearly about the process, and this often leads to devising ways of control. For example, research in meteorology has resulted in increased understanding of the processes involved in atmospheric disturbances but has not yet resulted in control over tornados and hurricanes. The research has, however, enabled developers to devise more precise forecasting of storms, which has aided in the design of protective actions.

Corresponding research on human learning has produced greater understanding of conditioning and of consciously directed learning, including such concepts as motivation, reinforcement, sequential practice, and transfer. This understanding has not immediately resulted in more effective teaching methods, instructional materials, and devices, but it has furnished a basis for clearer thinking about school learning that helps to give more intelligent direction to teaching.

Needed Research in Science Education

Reviewing contemporary activities in educational research and comparing them with the range of phenomena involved in science education, one is struck by their limited scope. Activities tend to be focused on school and college programs with a large proportion devoted to psychological analyses of the learners in the classroom. Little attention is given to science learning in the home, through television viewing, through job experiences, etc. In the early 1930s, George Stoddard and his colleagues at the University of Iowa showed how much information and misinformation children obtained from watching movies. At the same time, L. L. Thurstone and his group at the University of Chicago showed how powerful a movie could be in creating race prejudice. Some studies are now analyzing the content of television programs, but few attempt to determine empirically their effect upon different types of viewers. Programs like Superman, Spiderman, and the Incredible Hulk are popular with children, but little is known as to whether they increase children's beliefs in supernatural forces and magical persons or serve more as a relief from feelings of powerlessness because of the limitations imposed by natural forces.

Benjamin Bloom and his students have studied the differences in home environment and child-rearing practices in various kinds of families and have shown their relationship to language development in the school. More studies of home and local community environment would help to understand the process of science understanding or misunderstanding among American children and youth.

Few studies are reported on the learning that takes place in museums, libraries, nature clubs, etc. For these voluntary agencies in particular we need to know more about the attitudes children and adults have as they go to museums, libraries, and clubs. What kinds of children coming from what kinds of backgrounds are encouraged to participate in these activities because of interesting things they will learn, and what kinds are urged to go so that parents may shift responsibility for them for a time? We know from the studies of Robert Hess and his colleagues that many middle-class mothers send their children to school, saying, "You'll learn to read, write, and work with numbers so you can do things for yourselves. Do everything you can to learn!" He found many mothers in low-income homes saying to their children, "You've got to go to school. Don't do anything to get into trouble. We have enough trouble at home now." You can imagine the difference in the attitude toward school these two kinds of admonitions will produce. In the first, children are urged to be active and to learn; in the other, children are warned to be passive, with nothing said about learning. We need to understand the different attitudes learners have and the sources of those attitudes.

Little research has been done on the relationship between the public attitude toward science and the achievement of students. From the International Evaluation of Educational Achievement we find that the top 5 percent of the youth in each of the 13 developed nations participating made approximately the same high scores. However, the middle 50 percent of the students in each nation varied widely in their average scores, with Japan leading in science and the United States among the top three in reading. The scores of the lowest 25 percent of the students in the United States exceeded those of the lowest 25 percent of other countries. Our own national assessment of educational progress showed that in 1969-70, American 17-year-olds made higher scores in science than in 1972-74. This might be related to the fact that in 1969-70 the Americans were getting to the moon and the public was enthusiastic about scientific achievements. Four years later, pollution, energy limitations, and environmental degradation were widely publicized, and the respect for science had been replaced with the blaming of science and technology for these problems. One hypothesis is that young people who are deeply interested in a subject will learn a great deal about it if there is opportunity, regardless of the quality of the school. On the other hand, the middle group of students are strongly influenced in their learning by the public attitude toward the subject. In the United States, efforts to help "disadvantaged" children learn were apparently successful in terms of increased achievement of the lowest group, in spite of the public attitude.

More research is needed to identify how much science knowledge is important for young people who are not planning careers in science or in occupations closely related to science. The American Institutes for Research 1975 follow-up study of a sample of persons who were in high school in 1960 and participated in Project Talent is suggestive. These persons, who were in their thirties in 1975, were asked what they remembered, what they used, and what they thought was worth learning in their high school curriculum. With very few exceptions, the only things they remembered and thought worthwhile in their high school courses were those that they used in their work, such as mathematics in engineering, English composition in newspaper reporting, home economics in operating a restaurant, or subjects in which they were deeply interested. Science was listed as a subject of deep interest by very few who were not in occupations utilizing science.

Every subject in the school curriculum is an intellectual enterprise consisting of a great quantity of material. Not even the wisest scientist can know everything about his/her field. There are a number of basic concepts, a larger number of tested generalizations and principles, and thousands of facts. There are also many questions or problems being attacked, a fair variety of methods and techniques for conducting inquiries in this science, and many tools and instruments used. Furthermore, each science has developed standards of work and ethics that furnish important guides and constraints on the work of the scientist.

Which of all these things should be learned by whom? This question has not been seriously attacked in the last 50 years. The course-content improvement projects supported by the National Science Foundation (NSF) developed a prospectus of what was deemed important by the scientists directing the projects, but their efforts seem to have been focused on what students needed to learn at each stage of preparation for a career in science or in science-related occupations. The resulting courses are reported to have been successful in preparing more soundly the students who entered the college and graduate departments of science, but they did not attract or improve the science understanding of many of the students who were not planning to be scientists.

The relevance of science learning to the experiences, problems, and interests of the learner is an important matter not just for utilitarianism in a simplistic sense, but because of the nation's need for informed citizens in a world deeply involved in science and technology, and also because things learned are soon forgotten if there is not continued use of the learning in the learner's thoughts, feelings, or actions. The informed citizen cannot know as much as the scientist knows, but he will find some scientific understanding and attitudes essential to his role as a citizen in a democratic society. If this content can be identified, the learning can be accompanied by opportunities to apply it outside the classroom. Thus, transfer of learning as well as permanence of learning is more likely to be ensured.

Research is needed in science education--not only basic research which results in general concepts and principles, but also applied research, that is, inquiries focused on particular situations and particular kinds of students, teachers, and institutions, which furnishes information of importance in improving science education where necessary. For example, most teachers know that the peer group exerts a powerful influence on student learning; but the science teacher needs help identifying the peer groups in which his or her students are members and the groups' influence on science attitudes, interests, and understanding. Research may identify in general the relationship of public attitudes toward science and the science learning of students, but in a particular community the planning of a comprehensive science program requires knowledge of the various attitudes among members of the community, and how they relate to different kinds of learners. In other words, generalizations indicate significant factors involved in science learning. In the local setting, the educational practitioner needs particular knowledge of these factors and their impact. Some of these inquiries may be conducted by the practitioners or by the students themselves. But this is not likely to happen unless researchers furnish technical assistance to show how to conduct this applied research and how to utilize the findings of local inquiries.

This kind of connection between basic research and educational practice helps the practitioner understand that research can be helpful in efforts to improve education not embodied in development of a particular system for use by teachers or others in the classroom laboratory, home, museum, library, or other places where people learn. Research often identifies concepts, ways of thinking about a phenomenon that increase the effectiveness of the practitioner because he or she now observes significant things that were not perceived before or modifies his or her ways of working because the professional role is viewed differently. For example, recent research on "Time on Task" has influenced many teachers to observe the task orientation of students instead of noting only disruptive behavior.

Correspondingly, research results can be useful to developers as factors to consider in the design of a learning system, even though the system does not directly embody the research results. For example, research on social influences on learning has affected the design of a computer-managed instructional system, although the system is not in itself a social learning system.

The Function of Development in Education

Development in all fields is an activity seeking to design systems that will help to achieve purposes under given constraints. Thus, development in automobile engineering seeks to design cars that will carry passengers without polluting the atmosphere and with minimum gas consumption. As another example, development in the field of law enforcement includes an effort to design a system for police assignment that maximizes the proportion of offenses in which the police have arrived within 3 minutes and minimizes the number of patrolmen in each precinct. As these two illustrations show, a system may involve a tangible product or it may only involve designing a procedure.

In education, developers produce both tangible products and intangible systems. The development of single-concept mini-films with sound for science classes is an example of a product which is designed to help individual students understand the meaning and application of important concepts without requiring teacher attention to operation of the projector in a darkened room, nor the winding of a reel and periodic splicing of the film.

The development of an inquiry procedure in introducing a science unit is an example of an intangible system which can be followed by teachers without extended prior training in the use of an inductive approach to science learning.

Needed Developments in Science Education

Reviewing contemporary activities in educational development with the range of phenomena involved in science education, one is also struck by their limited scope. Activities tend to be focused on developing instructional materials and devices for school and college courses. Little attention seems to be given to the development of systems that could be used in the home and in other community institutions such as libraries, museums, and organizations of youth and adults. Only a small amount of development effort seems to be given to the development of systems that do not necessarily require tangible products.

Although teachers report that the problems of class management made individualization difficult, if not impossible, few development efforts are devoted to the design of effective management systems. The research of John Goodlad and his students indicates the great potential of continuous-progress learning policies, and the research of Benjamin Bloom and his students demonstrates the great increases in the achievement of the lower half of a class when mastery learning programs are adopted. Only a limited number of development activities that seek to develop systems to make more widely acceptable and effective continuous progress and mastery learning programs are found.

The explorations of older children teaching younger ones by Mary Kohler and the research on peer group instruction by Herbert Thelen have not been followed by systems developed to enhance the effectiveness of programs in which children and youth help to provide learning experiences for others. The same thing is true with regard to the potential contributions of adult volunteers as participants in student science learning.

Development activities are largely carried on without adequate contact with the potential users of the developments. During the past 70 years, a number of technological devices and systems that appear to offer major contributions to the effectiveness or efficiency of science learning have been invented and developed. Among the most widely known are motion pictures, radio, tape recorders, television, high-speed computers, videotapes and videodiscs. A considerable amount of research has been conducted on several of these devices to identify the kinds of educational contributions they can make, the results of which have generally indicated positive effects. In several cases, widespread promotional efforts were made to encourage their adoption in American schools. Yet their utilization is much more limited than was anticipated. In the public schools, educational motion pictures are among the common teaching aids, but their use is much more restricted than that of the overhead projector. Most of the other devices have found a significant place in only a small percentage of the classrooms.

Reviewing the examples, the use of typewriters by children in the primary grades was tested intensively by Freeman and Wood about 60 years ago. They found that it improved the children's performance in spelling, reading, and handwriting. There was a flurry of adoption of this innovation, but within 10 years only a few schools continued the practice.

The use of silent motion pictures was explored 50 years ago, quickly followed by experimentation with sound movies, which were heralded as the means for increasing learning and decreasing the costs of instruction. Today, sound motion pictures occupy an important but modest place among instructional aids, but there is little or no use now of films that are designed to furnish the complete instruction for a course. The use of radio in American schools has followed a very similar pattern after extensive experimentation in the 1930s.

On the other hand, some technological devices, like the overhead projector, caught on quickly and have been widely adopted. Some innovative systems such as multi-level reading laboratories have also been rapidly accepted and are now widely used. The difference between those innovations that are widely used and those that have not caught on lies in their perceived usefulness by the teacher and their comparative costs.

A typical teacher finds a new technology attractive when it will perform instructional tasks which he or she finds distasteful or boring. Teachers quickly adopt workbooks and audio tapes for drill and practice work. They also use computers for drill and practice when the school can afford them.

A typical teacher also finds a new technology attractive when it will help him or her to perform tasks which are recognized as important but which the teacher has not been able to perform effectively or easily. Most teachers feel a responsibility to provide instruction appropriate to the individual differences among their students but do not see how they can do this when they are responsible for a class of 25-35 students. Teachers are attracted to multi-level reading laboratories because they furnish reading materials appropriate for several different levels of reading development. Overhead projectors provide the flexibility of the chalk board to outline, explain, illustrate, or direct the student's attention without requiring the teacher to have highly legible handwriting or to turn his or her back to the class. The motion picture is attractive when the teacher wishes to present an event or a process more fully and vividly than is possible with printed or oral presentations.

There are negative features of innovations that developers also should recognize. Teachers do not believe that most students can learn what the schools and colleges seek to teach without the help of teachers. Hence, when materials are called "self-instructional" or "teacher-proof," teachers react unfavorably. Self-instructional materials meet a need of adults, but generally they will be used only as practice materials or homework in schools and colleges.

Devices or systems that appear complicated or that require extensive training for effective use are not likely to be used by most teachers unless they are given the necessary training. The development of easy-to-use film cartridges and tape cassettes greatly increased the use of motion pictures and tape recorders. Prior to that time, motion picture films required threading, rewinding, and sometimes splicing. Audio tapes also required rewinding and were likely to break if not handled expertly.

Another important factor in the use of innovative materials and devices is the cost. About 85 percent of the operating budget of a public school is for the salaries of teachers and other personnel. During the period 1945-75, only 1.5 percent was spent for instructional materials, and during the present inflationary period only seven-tenths of 1 percent of the annual operating budget is being spent for instructional materials. The amount of money available for equipment is no greater. Furthermore, the only way that a new device or new materials can save a significant amount of money is by replacing one or more teachers and thus reducing the size of the school staff. This would also mean increasing class size, and teachers do not generally favor such a policy. Hence, a device or system that is attractive must cost very little.

The foregoing analysis of the reaction of teachers and schools to educational developments is presented to indicate the importance of continuing contact between schools and teachers on the one hand and developers on the other to improve science education.

Training in the Use of Research and Development

Most educational improvement projects greatly underestimate the amount of training required for a typical potential user to employ the results of research and development. Several years ago, I served as a consultant to the Hebrew University of Jerusalem and Israeli Ministry of Education in projects involving the implementation of the Educational Reform Act of 1968. Considerable effort had been devoted to the development of instructional plans and new materials to aid teachers in following the new science programs, which were very similar to the course content improvement materials developed in the United States.

When the initial implementation projects were instituted in local schools, we found that [illegible] teachers did not understand the new objectives, did not know how to conduct inquiry learning, and did not believe that they could use these new materials effectively. They simply tried to use these new textbooks in the same way they had been using the old ones, that is, asking students to read and remember the materials in the books. Before the new programs were implemented in the schools in the ways intended by the developers, about 10 times as much had been spent in training and supervising initial efforts as had been expended on the research and development of the new courses.

In general, teachers, parents, librarians, and others who have a part to play in improving education will not undertake roles that they perceive as new unless they believe the new program will be significantly better than the present one, understand the procedures expected of them, have learned how to carry on new procedures, and feel confident that they can carry them on successfully. Most of them feel comfortable with their present practices and do not want to try something else which might mean failure. Most of the potential contributions of research and development activities to educational improvement will not be realized unless the training requirements are fully met. This involves greater expense and a longer time frame than is usually provided for in the planning and budgeting.

Communication in the Research and Development System

I use the word communication to emphasize the multi-directional channels needed to assist in the improvement of education. It has become popular to refer only to dissemination and diffusion, terms that imply one-way communication, from some centers of knowledge, new ideas, and new materials and devices to a passive audience that should be ready to receive the word from research and development centers. This is a faulty conception. As pointed out earlier, teachers are not passively waiting for things to be diffused to them. They are busy with their tasks and seek help only when they recognize a problem. This is also true of parents, librarians, museum curators, and other persons who are consciously or unconsciously stimulating and guiding learning. What is needed is a communication network that permits, encourages, and assists the flow of information from the places where science learning takes place to research and development centers, and the reverse flow from development and research centers. The Educational Resources Information Center (ERIC) provides a useful system to inform researchers and developers, but it is only a one-way system.

The leading industrial and commercial research and development centers include consumer research as an important function. An industry that produces office products, for example, conducts studies of such things as the activities in offices, the tasks performed, the problems encountered, and the efficiency of the operations. The results of these studies are used both to guide further applied research in seeking more adequate understanding of the office activities and to identify opportunities for developing new systems or products that can meet the perceived needs of potential customers. Both the applied research divisions and the development divisions attempt to keep in continuing touch with basic research concepts, principles, or instrumentation to furnish suggestions for applied research and for development. Even the basic research divisions try to understand consumer problems as a factor in selecting areas for further investigation.

To cite another example, at the present time major computer producers are increasing their activities in software development because the research on hardware has reached a point where the tremendous efficiency of computers is not matched by many apparent uses for them. Software development is an undertaking of both applied research and development to design systems employing modern computers that will help to solve important problems consumers recognize or could be helped to perceive. Computer companies are increasing their activities in customer training in order to help them to use computer systems effectively. These companies have established communication networks to aid in their research, both basic and applied, in development, in marketing, and in training. Although the processes of education are not so easily dealt with as typical office practices, it seems highly probable that science education could benefit markedly from a better integration of two-way communication systems among all the parts.

The most obvious weakness in the present communication system is the lack of opportunity for easy input by schools, homes, museums, libraries, and other places where science learning is going on presently or could be in the future. The Johnson 1964 Task Force on Education proposed education laboratories as a means for local education agencies to become an important part of the educational research and development system, and support for them was authorized in Title IV of the Elementary and Secondary Education Act of 1965. However, those that were established were more like research and development centers than laboratories helping and serving local schools. They often conducted research and developed instructional materials. Rarely did they conceive of themselves as representing local educational agencies, helping them identify significant problems, seeking relevant knowledge, ideas, materials, and devices to aid in attacking these problems, and communicating research needs to research and development centers. Whether this was due to a misunderstanding of the intentions of the legislation, to a belief that local agencies had no interest in research and development, or to the fact that most of the laboratories were staffed by university types oriented to theory rather than school types familiar with practice is not clear.

The need for closer working agreements between practice and research seems to be recognized by the National Science Foundation in another field. The Foundation reported on December 23, 1980:

> The Metropolitan Washington Council of Governments is planning a network of local governments in the mid-Atlantic Region to help solve municipal problems by applying scientific or technological techniques.
>
> Basically, the new network will be designed to enable cities and counties to improve the effectiveness or reduce the cost of specific services such as trash collection or fire and police efforts.
>
> The network will be a part of a National Innovation Network funded by the National Science Foundation's Division of Intergovernmental Science and Public Technology. The networks consist of groups of government officials, scientists, and technicians who help state and local governments solve day-to-day problems. The NSF program makes use of the scientific and technical expertise of universities, colleges, industries, and research institutions to help solve the cities' problems.

This network of innovation suggests a parallel kind of network for local educational agencies. It should probably not have "innovation" in the title. This term has been used so loosely and with such ill effects that teachers connect the term with poorly planned programs to improve education carried on in inappropriate settings by inadequately trained people to accomplish undefined objectives. Whether a network is established or some other form of cooperation among local agencies to identify and solve educational problems evolves, it is clear from the experiences with efforts to use research and development to improve education that the active involvement of practitioners is essential for widespread implementation.

In Summary

This paper has indicated some of the weaknesses in the present communication system linking educational practitioners with those engaged in research and development. It has suggested that both researchers and developers give attention to the several areas of life where people learn about science. It has asserted that practitioners should be viewed as active educators rather than as passive recipients of materials and advice from research and development centers and has identified some of the concerns on which teachers commonly focus their attention. It has also presented some examples of gaps in research and development efforts that limit the comprehensiveness of current knowledge of the systems designed to improve science education. It has pointed out the importance of adequate training for those who are to implement innovations. Finally, it has proposed a reconstruction of the communication system linking research, development, dissemination, and practice in science education.

INTEGRATED RESEARCH, DEVELOPMENT, DISSEMINATION, AND PRACTICE IN SCIENCE EDUCATION

Robert Karplus
Lawrence Hall of Science
University of California
Berkeley, California 94720

Dr. Robert Karplus is Professor of Physics and Associate Director of the Lawrence Hall of Science, University of California, Berkeley. The vast body of his writings in physics as well as in science education makes an introduction virtually unnecessary. Over the years since he received his Ph.D. at Harvard in Chemical Physics, he has been a Fellow at the Institute for Advanced Study at Princeton, a Guggenheim Fellow, a Fulbright Research Grantee, and has taught at Harvard, the University of Maryland, and M.I.T. He has received many awards for distinguished service, most recently, in October 1980, an Honorary Ph.D. from the University of Gothenburg. He has been the director of several NSF projects.

My remarks on the topic will reflect my background as a natural scientist whose point of view differs from that of behavioral scientists like Ralph Tyler. While reading his text, and now while listening this evening, I started to wonder what comes to mind when we discuss "research" in science education, or more generally, in education. Could you please think of a significant result of educational research, not obtained by yourself, that you trust sufficiently to use in your own work and to communicate to others?

Audience Suggestions

1. Wait Time research by Mary Budd Rowe and the value of Principle Learning in Biology, developed by Ralph Tyler.

2. Small groups working at a computer terminal together are superior to individuals working alone.

3. The difference between formal operational and concrete operational thinking.

4. The character of materials required to teach teachers how to teach reading.

5. Piaget's notion that knowledge always has to be built up by the learner and is not something that is transmitted from a sender to a receiver.

6. It pays to sell solutions to textbook problems along with textbooks.

7. Gagné's work on learning hierarchies.

8. The van Hiele classification of levels of complexity in explaining and understanding geometrical concepts.

9. The validity and operationalization of the psychological construct of general intelligence, starting from the work of Spearman, Binet, and Simon early in this century.

Thank you for all of these examples. I hope that they have clarified for you what various members of the group here have in mind when they use the term research as a basis for development and changes in teaching practice.

Before commenting further, I wish to mention a thought-provoking research result about which I learned recently. It has to do with the application to scientific literacy of the "Almond" model, which classifies the members of a country's population into four levels: decisionmakers, opinion leaders, the "attentive" public, and the "inattentive" public. The attentive public in an area like science policy includes those individuals who have basic knowledge in the area, who are interested in the area, and who engage in activities that allow them to keep informed and up-to-date on developments in the area. Jon Miller (1980) has found the attentive public in science to include between 15 and 20 percent of adults. Attentiveness is positively correlated with college attendance and the completion of a college science course. Miller suggests that there are so many competing interests appealing for a person's attention (e.g., economics, foreign policy, politics) that hoping to attract more than about 20 percent to one area is futile.

Now, to get back to Ralph Tyler's presentation. He pointed out that teachers are skeptical of much research because of its specialized nature. Let me elaborate on how I view some of the apparently intrinsic limitations of educational research.

It appears to me, for example, that there exists a tradeoff between the duration of a research project concerned with learning and the reliability with which its educational impact or significance can be determined. Short-term studies, such as surveys or cross-sectional tests, may be statistically impressive, but they are usually weak in taking into account the pre-existing conditions that lead individuals to respond the way they do or that even led to their participation in the project. The short-term studies also overlook further development of individuals after they have participated in the research. We physicists have encountered such tradeoffs even in our "exact" science and have formulated them as "uncertainty principles." One might therefore write

$$\Delta E \Delta T > \text{constant}$$

where ΔE is the uncertainty in the educational impact as measured in a research project that considered data describing its subjects during the time interval ΔT.

As another example, consider tradeoffs that arise from the influence of the process of measurement on its subjects. I experienced these myself when I generated physics problem-solving protocols. I found that I became more conscious of my private problem-solving processes after having articulated my procedures for tape-recording, and that my silent thinking often led me to skip over alternatives for intuitive and invalid reasons. Because of the slowness of speech, I also sometimes found myself thinking of such an alternative while still explaining the previous step and then having to decide whether I should mention the aborted trial or should go on to the next step. Thus, the very searching involvement of a subject will more greatly affect his/her thinking than a superficial questionnaire. Just as a wave packet confined to a small region of space has a very uncertain momentum, so the "mental state" or "knowledge" or "understanding" which researchers try to characterize becomes, in my judgment, a poorly defined construct when it is probed deeply.

So, there are limits of research. Hence, there is the need for a step between research and development to bridge the many gaps between the particular subject samples, questions, teaching procedures, and other circumstances of a research investigation and the much more diverse situations where the newly-developed educational product is expected to be useful. I shall call that step one of generalizing from research to form a system of conjectures, or, less respectfully, an ideology.

Look again at the nine items on the list of audience suggestions. Items 1, 3, 7, 8, and 9 refer to certain research results that describe observations made by the researchers in their work. As they stand, they do not provide explicit guidance for development of teaching materials. Items 2, 4, 5, and 6 are generalized statements that apply to teaching materials and procedures. I would therefore classify them as conjectures that go considerably beyond specific research results. Thus, when you think of research and development, you should really think of research that can be generalized and can lead to fruitful conjectures for development. Once teaching materials are developed, further research may clarify which aspects of the teaching materials make them effective or ineffective. In fact, I usually look for multiple conjectures, based on different research orientations, that lead to similar guidelines for activities development.

Consider, for instance, the active learning conjecture (Item 5), which has been the basis for much curriculum development during the last 20 years. In a recent AETS Yearbook (Lawson, 1979), scholars as diverse as Gagné, Kamii, Case, Lawson, Ausubel, Novak, Vargas, and I all advocate active learning for problem solving and the formation of other cognitive strategies. Most of us also recognize that such a learning program does not have highly specific predictable outcomes for all learners because the activity dimension encourages individual learners to have somewhat differing experiences. In spite of this remarkable agreement, however, active learning is not common educational practice because it conflicts with many of the general public's strong beliefs about the nature of learning. Yet active learning has attracted a persistent, though modest, following.

I will conclude my presentation with four matters that we must consider when we think of bringing about change in educational programs.

1. Textbooks, teachers, and tests form a mutually dependent system that is hard to modify. Texts are published for teacher acceptance and to enhance test performance; teachers are oriented to using existing texts and aim for achievement on tests; and tests are geared to the accomplishments of students using existing texts. Developers usually work on textbooks; teacher educators work with teachers. Not many people, I regret, work on novel testing approaches. Yet all three of these "T's" require attention.

2. Why should the schools teach science and mathematics? At the present time, the curriculum includes a little science and a great deal of arithmetic--math (other than arithmetic) and science are considered frills. Mathematics and science should be taught to prepare specialists, increase the attentive public for science, and develop reasoning, inquiry, and problem solving.

3. Consider what some authors have called the ecological approach to educational research and educational change (Sarason, 1971; Barker, 1968; Bronfenbrenner, 1979). The message of this approach is that anyone concerned with education or another social institution will benefit by looking beyond the immediate goals and circumstances of research. When you observe a high school student solving algebra word problems, for instance, keep in mind the various matters competing for the student's attention: yourself listening for an answer, possible plans for after-school games, or thoughts of a friend with whom to share lunch.

4. Science and mathematics teachers are themselves adults, who may be attentive or inattentive to science. The same holds true for parents. Thus, as J. Easley (1981) has pointed out, one generation affects the next, and the ways in which we select students to become teachers has an important bearing on what can be achieved in science and mathematics education.

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INTEGRATED RESEARCH, DEVELOPMENT, DISSEMINATION AND PRACTICE IN SCIENCE EDUCATION

Ronald G. Havelock
Knowledge Transfer Institute
American University
Washington, D.C.

Dr. Ronald Havelock received his B.A. degree in History from Harvard University and his Ph.D. in Social and Personality Psychology from Boston University. He has devoted his career to the study of the process of research utilization. The 1969 volume on Planning and Innovation provided a comprehensive state-of-the-art review on research dissemination and utilization, and proposed a linkage framework for future studies and analyses. After serving a number of years as Director in the Institute for Social Research at the University of Michigan, Professor Havelock recently came to the American University to assume a position on the faculty in the Center for Technology and Administration. He has also established an institute within the University devoted to the study of knowledge transfer. His most recent book, entitled Solving Educational Problems, was published by Praeger in 1978. It examines the processes of innovation and the role of outside agencies in developing countries.

Let me begin by praising and enthusiastically endorsing the thrust of Dr. Tyler's remarks. Let me then take the liberty of slightly rephrasing one of his main points thus: there is a need to develop more effective linkage between research and teaching in science education. What more effective linkage really means is an extensive, intensive, and continuing dialogue between researchers and teachers in which (1) teachers learn to value the diverse ways in which research knowledge and a research-oriented approach to problems can be used, and (2) at the same time researchers develop a more grounded understanding of the situational press of the teacher and the genuine needs of the teacher within the classroom setting. If such a dialogue could be achieved on a large scale involving many thousands of teachers and researchers, there would be a double benefit in vastly improved and more relevant research and development on the one hand, and widespread and sophisticated use of the research knowledge now available on the other. What is being asked for is a dynamic partnership between teachers and researchers.

Building on Dr. Tyler's comments, how might we proceed operationally toward such worthy ends? We can look to other sectors of education and to other fields for a variety of models or institutional arrangements which at least partially achieve such goals. Looking first to a familiar historic model, we have the elaborate sequence of interconnections which constituted the work of the Physical Science Study Committee (PSSC). This was really a major development effort inspired by an academic elite but which genuinely involved the collaboration of high school teachers, university experts, and scholars, and it resulted in a very widespread reform of high school physics teaching. The model was subsequently copied in many respects in the development of other curriculum materials for other subjects.

Yet the PSSC model, I would guess, does not fill the bill for what Dr. Tyler is talking about. First of all, it was not a continuing process which involved a very large number of teachers in true collaboration with experts. Rather, it was a special project which had the clear goal of establishing a standard curriculum, not an individualized teacher-adapted and student-adapted program. Furthermore, it tended to be elitist in both conception and consequence providing a high quality of physics education for those who took physics but in no way broadening the spectrum of students who were either likely to take physics or to be imbued with a better understanding and appreciation of the values of science.

But there are other models. One approach is to leave the researchers alone and to insert new kinds of specialist roles between research and practice, roles such as developer, demonstrator, facilitator, linker, and so forth. The institutionalization of such roles has been a preoccupation of certain offices within the Department of Education over the last decade. Dr. Tyler mentions the regional educational laboratories established under authority of the Elementary and Secondary Education Act of 1965. He notes correctly that they have failed to fill the kind of linking function that is needed, but I perceive their history rather differently.

First, there was never enough financial support for these institutions to play such a role on a meaningful scale, and, partly for this reason, their mission was defined more in terms of product development than in terms of dissemination and utilization of research and development. There were originally only 20 of these labs and later the number was cut drastically; thus, each served a very large region of several states and many hundreds of school districts. The kinds of practitioner-centered, hands-on assistance from the research side which Dr. Tyler proposes simply could not be performed within their resource constraints. Therefore, I think the development for diffusion through more depersonalized and commercial channels made some sense even if it was admittedly less powerful.

As we progressed into the 1970s, however, it became more and more evident that the private sector had little interest in the active diffusion of the kinds of products which emanated from the labs, and the labs responded by focusing more and more on establishing their own channels to users. They did this in at least two ways. One was to establish an inter-lab consortium to promote the dissemination of lab products and of research and development knowledge in general. Usually, this was done through establishing stronger relationships with the state education agencies. Another approach was to identify a few key client groups, again, sometimes at the state level, sometimes in city or county school districts, and to work with these clients in a much more dialogic way, assessing needs on an ad hoc basis and providing a range of services and technical support related to changes that were mutually decided upon and mutually developed. This model, which the National Institute of Education (NIE) has dubbed the "regional services program," seems much closer to what Dr. Tyler is talking about, but, of course, such efforts rarely focus on science education.

I would also like to call your attention to another federally supported initiative which many of you may already know about, the National Diffusion Network. This program had its origin in Title III of ESEA, a section of the law which spawned literally thousands of locally initiated projects throughout the country on almost every conceivable subject related to educational reform or improvement. By the early 1970s, the Federal Government began to turn its attention to the problem of how the collective experience and wisdom deriving from such projects could be shared nationally.

The solution which emerged has three critical elements. The first is a screening mechanism, a panel of experts on program evaluation which sat as a jury to decide which project could truly show evidence of desirable outcomes. Approved projects (there are by now well over 200) were then allowed to compete for funded status as "developer/demonstrators." Such funds would enable them to prepare dissemination and training materials, go around the country creating awareness, and provide some techical assistance to other districts wishing to adopt the same or a similar program. The third element in this network arrangement is the state facilitator, again a funded project whose purpose is to spread awareness of all approved developer/demonstrator projects within a state. This statewide project facilitates access and connection between districts with a particular interest and need and the appropriate demonstration project. The model seems to work rather well for diffusing certain types of innovations, but whether it encourages the kind of creative and collaborative problem-solving which Dr. Tyler has suggested is not clear.

We should be reminded of the very great success in U.S. agriculture over the last century in building up an effective infrastructure which simultaneously serves practitioners and builds a large and sound research and development base. As a linkage system we could say the Cooperative Extension Service is the oldest, most elaborate, most expensive (though cooperatively funded), and probably the most successful ever developed anywhere to serve a large and decentralized practitioner group. Certainly nothing like it exists in education, medicine, law, or commerce. Regrettably, such a system is not in the cards for us just now. Nevertheless, there are some principles from the agricultural experience on which we can build.

First is the notion that the university is a resource which can be used in diverse ways to train, coordinate, and provide technical expertise. Second is the notion that funding can be cooperative and that the university can act as a responsible fiscal agent for such cooperation. Third is the notion that a system of knowledge creation and delivery can be orchestrated to produce very positive results for the society as a whole.

There are, indeed, a few modest prototypes within education which have some of these features. For the last two years we have been studying network arrangements which connect schools and teachers to one another and to expert knowledge sources through the ongoing mediation of a university. The oldest of these actually dates back to 1941 when Professor Paul Mort of Teachers College at Columbia founded a consortium of rather wealthy school districts in the New York metropolitan area. This consortium was dedicated to collaborative self-improvement through the sharing of innovative practice, the rigorous collection and comparison of performance data within a common framework, and the utilization of resultant findings. Through Mort's inspired leadership, this network expanded and thrived over a 30-year period and still exists today in a modified form some 20 years after his death. Although Mort's special concern was administration and school finance, he showed what could be done in a collaborative inter-institutional arrangement with a university core. As colleges and universities today struggle with declining enrollments, they might well look to the Mort model as a way of redefining their mission, increasing their relevance and utility to practice, and upgrading their capacities for truly relevant research and development.

In closing, I would note with some regret that many of the alternative models of linkage which I have cited have not been applied in the field of science education, even when they have proved rather successful for other educational fields. I think Dr. Tyler is urging us to develop some serious linkage models, perhaps uniquely adapted to science education. In so doing, we should look long and hard at the rather rich and varied experience which has been gained to date in other fields.

THE ROLE OF THE NATIONAL DIFFUSION NETWORK IN SPREADING EDUCATIONAL INNOVATIONS

Lee E. Wickline
U.S. Department of Education
Washington, DC 20202

In 1974 Dr. Lee E. Wickline developed the now well known National Diffusion Network, and he serves as its Director in the Office of Educational Research and Development in the Department of Education. His professional career has been in education, ranging from science education, his specialty, to general education for refugees, bilingual education, and efforts to keep would-be dropouts in school. He has published science source books for both junior high and elementary school teachers as well as other works dealing with educational measurement and instruction. He holds degrees from Concord College and West Virginia University, and took his doctoral degree in education at Pennsylvania State University.

To capitalize on its multimillion-dollar investment over the past two decades in supporting education research and the discovery and development of innovative education processes and products, the then U.S. Office of Education in 1974 created a unique dissemination system, the National Diffusion Network (NDN). The NDN disseminates information about, and promotes the adoption of, exemplary programs, projects, and materials which have been judged effective by a panel of evaluation and program experts, the Joint Dissemination Review Panel (JDRP).

The National Diffusion Network differs in several ways from other approaches to educational dissemination and change. First, the goal of the NDN is to effect the widespread adoption and implementation of innovations validated by the JDRP, as opposed to simply disseminating descriptive information regarding projects and practices.

Second, the National Diffusion Network uses two types of change agents in accomplishing this goal. The first type, the developer/demonstrator, is a change agent who operates a JDRP-approved project as a demonstration and who provides materials, training, and assistance to school districts interested in adopting that project. The other type of change agent funded by the National Diffusion Network is the state facilitator. The state facilitator, in contrast to the developer/demonstrator, is a change agent who works within a specific region, in most cases an entire state. State facilitators provide a link between developer/demonstrators and local schools, They identify potential adopters, establish communication between the developer/demonstrator and potential adopters, and assist in the adoption process.

The Joint Dissemination Review Panel (JDRP) was established by the then U.S. Office of Education to examine evidence from education projects or products that claim effectiveness in attaining their goals. Any project or product approved by the panel is thereby eligible to compete for dissemination funds from the National Diffusion Network. JDRP review can benefit a project in several ways, whether the project is finally approved by the panel or not:

- Evaluation data collected along JDRP guidelines can give a project, as well as the panel, effective tools for evaluating the program.
- The Joint Dissemination Review Panel gives an objective view of a project and can offer suggestions for improvement in its evaluation.
- Approval by the JDRP brings recognition of a program's accomplishments from colleagues on local, state, regional, and national levels and is an affirmation of the professional accomplishments of the project's developers. Approval also brings positive recognition from the public for the developing school or institution.
- Once reviewed by the JDRP and approved for dissemination, a project is eligible for entry into the National Diffusion Network and may compete for dissemination funding. If funded for dissemination, the program could be adopted in many schools throughout the United States or even in other countries.

To be approved by the JDRP, a program must submit reasonable, objective, and convincing evidence that it is causing significant and positive changes in the group it affects, and must demonstrate the feasibility of reproducing the program in other sites. When a project is presented to the JDRP, the following types of questions are likely to be asked:

(1) Has a positive change occurred? What is your evidence of change (for example, changes in test scores, improved student behavior or attitude, cost savings to the school, changes in attendance records)?

(2) Can the change be attributed to your program rather than to other causes such as normal maturation, regular education programs, or other factors?

(3) Is the change large enough and observed often enough to be statistically significant?

(4) Is the change educationally significant? What is the size of the change, and what is the importance of the area in which change has occurred? Is the cost reasonable, considering the magnitude and area of change?

(5) Has the evidence supporting the program's claims been gathered and interpreted correctly?

(6) Can the program be used in other locations with comparable impact?

The Federal government is currently funding 139 developer/demonstrator programs in the National Diffusion Network for the purpose of helping schools and other organizations adopt them. This is in addition, of course, to the state facilitators funded by the NDN in all states and territories but Wyoming and Puerto Rico to assist the schools in their states that want to learn about and adopt NDN programs. All programs approved by the Joint Dissemination Review Panel are described in NDN's annual publication entitled Education Programs That Work. This publication is available from Far West Laboratory for Educational Research and Development, 1855 Folsom Street, San Francisco, California 94103, for $5.50, prepaid.

One of the National Diffusion Network's biggest accomplishments is its record of cost effectiveness. The Federal government invested almost $66 million to develop 124 of the NDN's programs. Developmental funding for those programs ranged from $2,000 to more than $12 million, with a median cost of $248,642. These programs are currently being installed in adopting school districts through the NDN at a cost to the Federal government of approximately $4,000-$5,000 each. The amount a school district needs to adopt an NDN program for one of its schools ranges from $1 to $4,335 per pupil. The higher figure reflects the cost of certain programs for the severely handicapped. The median per pupil cost for schools to adopt NDN programs in 1979-80 was $12. During school year 1979-80, a total of 11,069 schools adopted developer/demonstrator programs funded by the National Diffusion Network.

Basic skills and early childhood education are currently the focus of more than one-half of the developer/demonstrator programs available for adoption. The National Diffusion Network, however, is also firmly committed to the need to disseminate programs in the areas of science, social studies, and environmental education. The NDN currently funds 10 programs in those areas and is constantly seeking new, innovative, effective science programs to present to the Joint Dissemination Review Panel for validation. Professionals in the field of science and those familiar with educational programs in the area of science can facilitate the NDN's effort to identify more successful programs by disseminating information about the NDN to their colleagues and by bringing to our attention the names of individuals and agencies that have exemplary programs in operation.

Among the science, math, social studies, and environmental education programs represented in the National Diffusion Network is the Individualized Science Instructional System Dissemination Project (ISIS). ISIS is an interdisciplinary, modular science program preparing students who do not plan to major in postsecondary science to understand practical, real-world, science-related problems.

The ISIS program consists of 52 short, independent minicourses, 34 of which currently have JDRP approval. The courses cover a broad range of topics of practical significance and are intended to help students meet the diverse needs of today's world. Since the minicourses are independent, they can be used separately or grouped to form year-long courses representing the traditional science areas of life science, general science, chemistry, and physics or to form a multidisciplinary course. Individual minicourses cover topics related to health, physical education, ecology, and social science, as well as the traditional science areas.

Each minicourse, its accompanying test items, and all ancillary materials were reviewed for their science content at every stage of development and testing by at least two scholars considered to be experts in the content discipline. The materials were also reviewed by a panel from the National Congress of Parents and Teachers, who judged them for bias and appropriate treatment of sensitive issues.

The ISIS program, which was originally developed with funding from the National Science Foundation and was validated by the Joint Dissemination Review Panel on April 17, 1979, was successful in securing 96 adoptions during the 1979-80 school year.

Another science program funded by the National Diffusion Network is Project I-C-E (Instruction-Curriculum-Environment) which offers a total kindergarten-through-12th-grade curriculum and instruction package for environmental education. Its primary goal is to lead students directly or subtly to awareness, appreciation, recognition, and action regarding the vital issues, concerns, and factors shaping environmental attitudes and values.

Twelve major environmental concept categories provide a framework for the program, as well as for each grade level and subject area. The entire program is neither scientifically nor technically oriented, but is based on the assumption that all teachers can and should teach environmental concepts and that all disciplines (subject areas) must be used to reinforce environmental learning.

Through the use of a supplementary episode design, the learning activities may be integrated into traditional courses of study by substitution of content or activity; hence the program does not make additional instructional demands on teachers. Project I-C-E, which was validated by the Joint Dissemination Review Panel on May 14, 1975, was originally developed with USED ESEA Title III funding. During the 1979-80 school year, Project I-C-E was successful in achieving 119 new adoptions.

One final example of a science-related project funded by the National Diffusion Network is the Comprehensive School Mathematics Program which was developed with ESEA Titles III and IV funding, as well as funding from the National Institute of Education. CSMP, as the program is commonly known, was validated by JDRP on March 17, 1978.

CSMP is an exciting, complete elementary-level mathematics curriculum from basics to problem solving for students of all ability levels. An underlying assumption of the CSMP curriculum is that children can learn--and can enjoy learning--much more math than they do now. Unlike most modern programs, the content is presented not as an artificial structure external to the experience of children, but rather as an extension of experiences children have encountered in their development both at the real-life and fantasy levels. Using a pedagogy of situations, children are led through sequences of problem-solving experiences presented in game-like and story settings. It is CSMP's strong conviction that mathematics is a unified whole and should be learned as such. Consequently, the content is completely sequenced in spiral form so that each student is brought continuously into contact with each area of content throughout the program, while building interlocking experiences of increasing sophistication as the situations become challenging. A feature unique to CSMP is the use of three nonverbal languages which give children immediate access to mathematical ideas and methods necessary not only for solving problems, but also for continually expanding their understanding of the mathematical concepts themselves. The CSMP program was adopted in 32 sites during school year 1979-80.

The programs described herein are representative of the ten science-related and eight mathematics programs currently funded for dissemination by the National Diffusion Network. It is our sincere intention to actively seek new programs in these areas and to facilitate their validation by the Joint Dissemination Review Panel in order that they might compete for dissemination funding.

To secure further information, nominate a program for validation, or obtain technical assistance from the National Diffusion Network, please contact me, Dr. Lee Wickline, Room 802, Riviere Building, 1832 M Street, N.W., Washington, DC 20036, telephone (202) 653-7000. You may also refer to the attached list of NDN State Facilitators and contact the appropriate state or regional facilitator directly.

State Facilitators

National Diffusion Network
1980-81

ALABAMA
R. Meade Guy
Alabama Facilitator Project
Alabama Information and
Development System (AIDS)
Alabama Department of Education
Room 347, State Office Building
Montgomery, AL 36130
(205) 832-3138

ALASKA
J. Kelly Tonsmeire
Alaska State Facilitator Project
Alaska Department of Education
Pouch F, State Office Building
Juneau, AK 99811
(907) 465-2814 or 2815

ARIZONA
L. Leon Webb
Arizona State Facilitator
Educational Diffusion Systems, Inc.
161 East First Street
Mesa, AZ 85201
(602) 969-4880

ARKANSAS
Emil R. Mackey
Arkansas State Facilitator Project
Arkansas Department of Education
Communication and Dissemination
Division
State Capitol Mall
Little Rock, AR 72201
(501) 370-5038

Regional Facilitators
Mary B. Gunter
Arkansas State Facilitator Project
Region 1
Boston Mount Cooperation
P.O. Drawer 248
Prairie Grove, AR 72753
(501) 846-2206

Ora Stevens
Arkansas State Facilitator Project
Region II
Marianna School District
P.O. Box 309
Marianna, AR 72360
(501) 295-5291

CALIFORNIA
Ira Barkman or Ginna Lurton
California State Facilitator
State Department of Education
Exemplary Program Replication
Unit
721 Capitol Mall
Sacramento, CA 95814
(916) 322-6797

COLORADO
Duane C. Webb
Colorado State Facilitator
830 South Lincoln
Longmont, CO 80501
(303) 772-4420 or 442-2197

CONNECTICUT
Carolyn McNally
Connecticut Facilitator Project
Area Cooperative Educational
Service
800 Dixwell Avenue
New Haven, CT 06511
(203) 562-9967

DELAWARE
Peter Bachmann or Wilmer E. Wise
Delaware Facilitator Project
Planning, Research & Evaluation
Division
State Department of Public
Instruction
John G. Townsend Building
P.O. Box 1402
Dover, DE 19901
(302) 736-4583

DISTRICT OF COLUMBIA
Susan Williams
District Facilitator Project
Jackson School
31st and R Streets, NW
Washington, DC 20007
(202) 544-5822 or 298-9030

FLORIDA
G. Michael Kuhn
State Facilitator for the
Department of Education
Knott Building
Tallahassee, FL 32301
(904) 487-1078

GEORGIA
India Lynn King or Mary Allison
Georgia Facilitator Center
226 Fain Hall
University of Georgia
Athens, GA 30602
(404) 542-3332

HAWAII
Kellett Min
Hawaii State Facilitator
Hawaii State Department
of Education
P.O. Box 2360
Honolulu, HI 96804
(808) 548-3425

IDAHO
Ted L. Lindley
Idaho State Facilitator
Idaho State Department of
Education
Len B. Jordan Office Building
Boise, ID 83720
(208) 334-2189

ILLINOIS
Shirley M. Menendez
Illinois Statewide Facilitator
1105 East Fifth Street
Metropolis, IL 62960
(618) 524-2664

INDIANA
Ted F. Newell
Indiana Facilitator Center
Logansport Community
School Corp.
2829 George Street
Logansport, IN 46947
(219) 722-1754

IOWA
David C. Lidstrom
Iowa State Facilitator
Iowa Department of Public
Instruction
Grimes State Office Building
Des Moines, IA 50319
(515) 281-3111

KANSAS
James H. Connett
Kansas State Facilitator Project
KEDDS/LINK
1847 N. Chautauqua
Wichita, KS 67214
(316) 685-0271

KENTUCKY
John C. Padgett
Kentucky State Facilitator
State Department of Education
Capitol Plaza Tower Office
Building
Frankfort, KY 40601
(502) 564-4394

LOUISIANA
James R. Owens, Jr.
The Louisiana Facilitator Project
Louisiana State Department of
Education
ESEA Title IV Bureau Office
P.O. Box 44064
Baton Rouge, LA 70804
(504) 342-3375

MAINE
Robert G. Shafto
Maine Facilitator Center
P.O. Box 1391
Gardiner, ME 04345
(207) 582-7211 or 7212

MARYLAND
Raymond H. Hartjen
Maryland Facilitator Project/
Educational Alternative, Inc.
P.O. Box 265
Port Tobacco, MD. 20677
(301) 934-2992

MASSACHUSETTS
John Collins
Massachusetts State Facilitator
The NETWORK, Inc.
290 South Main Street
Andover, MA 01810
(617) 470-1080

MICHIGAN
Deborah Clemmons
Michigan State Facilitator
Michigan Department of Education
P.O. Box 30008
Lansing, MI 48909
(516) 373-1806

Regional Supplemental Centers
William Banach
Educational and Management
Improvement Center
44001 Garfield Road
Mt. Clemens, MI 48043
(313) 286-8800

Ron Berg
Cheboygan-Otsego-Presque Isle ISD
Basic Regional Supplemental Center
6065 Learning Lane
Indiana River, MI 49749
(616) 238-9394

Richard D. Anderle
Kent Intermediate School District
Region 8 Supplemental Center
2650 East Beltline, SE
Grand Rapids, MI 49506
(616) 957-0250

Roy Butz
Oakland Intermediate School District
2100 Pontiac Lake Road
Pontiac, MI 48054
(313) 858-1940

Gerry Geik
Kalamazoo Valley Intermediate
School District
Region 12 Supplemental Center
1819 E. Milham Road
Kalamazoo, MI 49002
(616) 381-4620 ext. 247

Bobbie Ann Robinson
Saginaw Intermediate School
District
MERC (Mid-Eastern Regional
Consortium)
6235 Gratiot Road
Saginaw, MI 48603
(517) 799-9071

Polly Friend
Marquette-Alger Intermediate
School District
427 W. College Avenue
Marquette, MI 49855
(906) 228-9400

Olga Moir
Wayne County Intermediate
School District
Project VALUE
33500 Van Born Road
Wayne, MI 48184
(313) 326-9300

Shirley Rappaport
Bay-Arenac Intermediate School
District
Region 6 Supplemental Center
4228 Two Mile Road
Bay City, MI 48706
(517) 686-4410

Sylvia Ruscett
Ottawa Intermediate School
District
13565 Port Sheldon Road
Holland, MI 49423
(616) 399-6940 ext. 359

MINNESOTA
Gene Johnson or James Christianson
Northern and Central Minnesota
State Facilitator Project
Educational Cooperative Service
Unit 5
102 N.E. Sixth Street
Staples, MN 56479
(218) 894-1930

Diane Lassman
Southeast Minnesota Facilitator Project
The EXCHANGE
166 Peik Hall
University of Minnesota
Minneapolis, MN 55455
(612) 376-5297

Richard L. Peterson
State Facilitator Project
ESCU Office
Southwest State University
Marshall, MN 56258
(507) 537-1481

MISSISSIPPI
Jerome P. Brock
Mississippi Facilitator Project
Bankers Trust Plaza Building
Suite 1112
P.O. Box 1801
Jackson, MS 39205
(601) 948-1210

MISSOURI
Jolene Schulz, Director
Missouri State Facilitator Center
310 North Providence Road
Columbia, MO 65201
(314) 443-2561 ext. 218/238
or 449-8622

MONTANA
William E. Connett or
Wayne Pyron
Montana State Facilitator Project
Office of Public Instruction
State Capitol
Helena, MT 59601
(406) 449-3693

Regional Facilitators
Cliff Harmala
Montana Regional Facilitator
1011 N. River Avenue
Glendive, MT 59240
(406) 365-4422 or 449-5643

Jim Palmer
Montana Regional Facilitator
P.O. Box 3836
Missoula, MT 59806
(406) 251-4923

Jim Watkins
Montana Regional Facilitator
1325 Fourth Avenue North
Great Falls, MT 59401
(406) 761-4144

NEBRASKA
Mary Lou Palmer
Nebraska State Facilitator Project
Nebraska State Department of Education
301 Centennial Mall
P.O. Box 94987
Lincoln, NE 68509
(402) 471-2637

NEVADA
Victor Hyden
Nevada State Facilitator Project
Nevada Department of Education
400 West King Street
Capitol Complex
Carson City, NV 89710
(702) 885-5700

NEW HAMPSHIRE
Jared Shady
New Hamsphire Facilitator Center
80 South Main Street
Concord, NH 03301
(603) 224-9461

NEW JERSEY
Joseph Picogna
New Jersey State Facilitator Project
Title IV Director
New Jersey State Department of Education
225 West State Street
Trenton, NJ 08625
(609) 292-5792 or 8736

NEW MEXICO
Amy Atkins, Director, or
Susan Carter, Assistant Director
DEEP: Diffusing Exemplary Educational Practices in New Mexico
Department of Educational Foundations
College of Education
University of New Mexico
Albuquerque, NM 87131
(505) 277-5204

NEW YORK
Samuel Corsi, Jr.
New York State Facilitator Project
Office of Federal Demonstration Programs
Room 860
Educational Building Annex
New York State Education Department
Albany, NY 12188
(518) 474-1280

Regional Facilitators

John T. Donovan
OEP Representative
410 East Willow Street
Syracuse, NY 13203
(315) 425-4284

Grace Fairlie
Supervisor of Curriculum Development
756 St. Lawrence Avenue
Buffalo, NY 14216
(716) 833-5865

Evelyn Jones
Office of Special Projects
347 Baltic Street
Brooklyn, NY 11201
(212) 624-2273

Eleanor Peck
Program Analyst
City School District
Office of Urban Funded Programs
131 West Broad Street
Rochester, NY 14608
(716) 325-4560

Robert Raub
Madison-Oneida BOCES
Spring Road
Verona, NY 13478
(315) 363-8000

Richard Solomon
555 Warren Road
Ithaca, NY 14850
(607) 257-1555

Arthur Sullivan
Suffolk County BOCES III
507 Deer Park Road
Dix Hills, NY 11746
(516) 549-4900

Frank Thompson
Project Director
ECOS Training Institute
Box 369
Yorktown Heights, NY 10598
(914) 245-6919

Charles Weed
Regional Planning Center
1015 Watervliet-Shaker Road
Albany, NY 12205
(518) 456-9281

NORTH CAROLINA
Henry A. Helms, Jr.
Division of Development
North Carolina Department of Public Instruction
Education Annex No. 1
Raleigh, NC 27611
(919) 733-7018

Regional Facilitators

Glen Arrants
North Carolina Facilitator Center
Paton School
102 Old Clyde Road
Canton, NC 28716
(704) 648-6960 ext. 31

Richard Barnes
North Central Regional Education Center
P.O. Box 21889
Greensboro, NC 27402
(919) 379-5764

Maxine Brown
Northeast Regional Education Center
Box 1028
Williamston, NC 27892
(919) 792-5166

Robert R. Byrd
North Carolina Facilitator Service
Southwest Site
619 Wall Street
Albemarle, NC 28001
(704) 983-2127

Brenda Dail
Central Regional Education Center
Box 549
Knightdale, NC 27545
(919) 266-9282

Josephine Spaulding
South Central Regional Center
P.O. Box 786
Carthage, NC 28327
(919) 947-5871

Joe Webb
Southeast Regional Facilitator Service
Education Center, Room 200
612 College Street
Jacksonville, NC 28540
(919) 455-8100

James Sineon
Northwest Regional Center
303 "E" Street
North Wilkesboro, NC 28659
(919) 667-2191

NORTH DAKOTA
Hank Landeis
North Dakota State Facilitator
Department of Public Instruction
State Capitol
Bismarck, ND 58505
(701) 224-2293

OHIO
Gordon Behm
Ohio Facilitation Center
The Ohio Department of Education
Division of Planning and Evaluation
65 South Front Street, Room 804
Columbus, OH 43215
(614) 466-3825

OKLAHOMA
Kenneth Smith
Oklahoma Statewide Facilitator Project
Edmond Public Schools
1216 South Rankin
Edmond, OK 73034
(405) 341-2246

OREGON
Dick Pedee
Oregon State Facilitator
Multnomah County Education Service
District
220 S.E. 102nd Avenue
Portland, OR 97216
(503) 254-9925

PENNSYLVANIA
Richard Brickley or Carolyn Trohoski
R.I.S.E.--Pennsylvania State Facilitator
198 Allendale Road
King of Prussia, PA 19406
(215) 265-6056

RHODE ISLAND
George McDonough
State Facilitator Center--R.I.S.F.C.
CIC Building
235 Promenade Street
Providence, RI 02908
(401) 277-3840 or 3841

SOUTH CAROLINA
James R. Buckner or
Sharon Ray
South Carolina Facilitator Project
South Carolina State
Department of Education
Office of Federal Programs
1429 Senate Street
Columbia, SC 29201
(803) 758-3526

SOUTH DAKOTA
Gene K. Dickson
South Dakota State Facilitator
South Dakota Division of
Elementary and Secondary
Education
Richard F. Kneip Building
Pierre, SD 57501
(605) 773-3395

TENNESSEE
Martin McConnell or
Charles M. Achilles
Tennessee Statewide Facilitator
Project (TSF)
College of Education/BERS
2046 Terrace Avenue
University of Tennessee
Knoxville, TN 37916
(615) 974-4165 or 2272

TEXAS (cont.)
William Scanell
Texas Education Agency
201 East 11th Street
Austin, TX 78701
(512) 475-5601

Robert Reeves
Region I Education Service Center
Diffusion Project
1900 West Schunior
Edinburg, TX 78539
(512) 383-5611

Madalyn Cooke
Region II Education Service Center
209 North Water
Corpus Christi, TX 78401
(512) 883-9288

Bill Powell
Region III Education Service Center
1905 Leary Lane
Victoria, TX 77901
(512) 575-1471

Charlie Henderson
Region IV Education Service Center
P.O. Box 863
Houston, TX 77001
(713) 868-1051

Edith Peacock
Region V Education Service Center
2295 Delaware Street
Beaumont, TX 77703
(713) 835-5212

Everett Youngblood
Region VI Education Service Center
3332 Montgomery Road
Huntsville, TX 77340
(713) 295-9161

Mike Owens
Region VII Education Service Center
P.O. Drawer 1622
Kilgore, TX 75662
(214) 984-3071

Leroy Hendricks
Region VIII Education Service Center
100 North Riddle Street
Mt. Pleasant, TX 75455
(214) 572-6676

Art Phillips
Region IX Education Service Center
301 Loop 11
Wichita Falls, TX 76305
(817) 322-6928

State Facilitator
Region X Education Service Center
400 East Spring Valley Road
P.O. Box 1300
Richardson, TX 75080
(214) 231-6301

Mary F. Hull
Region XI Education Service Center
3001 North Freeway
Fort Worth, TX 76106
(817) 625-5311

Rosemary Richards
Region XII Education Service Center
401 Franklin
Waco, TX 76703
(817) 756-7494

Carrie Heim
Region XIII Education Service Center
7703 North Lamar
Austin, TX 78752
(512) 458-9131

Robert E. Maniss
Region XIV Education Service Center
P.O. Box 3258
Abilene, TX 79604
(915) 677-2911

Nancy Lowe
Region XV Education Service Center
P.O. Box 5199
San Angelo, TX 76902
(915) 655-6551

Jack Shelton
Region XVI Education Service Center
1601 South Cleveland
P.O. Box 30600
Amarillo, TX 79120
(806) 376-5521

Travis Brown
Region XVII Education Service Center
4000 22nd Place
Lubbock, TX 79410
(806) 763-4127

Bill Whitfield
Region XVIII Education Service Center
P.O. Box 6020
Midland, TX 79701
(915) 563-2380

State Facilitator
Region XIX Education Service Center
P.O. Box 10716
El Paso, TX 79997
(915) 779-3737

Betty Child
Region XX Education Service Center
1550 N.E. Loop 410
San Antonio, TX 78209
(512) 828-3551

UTAH
Kenneth P. Lindsay
Utah State Facilitator Project
Utah State Office of Education
250 East Fifth South
Salt Lake City, UT 84111
(801) 533-5431

VERMONT
Joseph M. O'Brien
Vermont State Facilitator
Bennington-Rutland Supervisory Union
Manchester Center, VT 05255
(802) 362-2452

VIRGINIA
J.B. Linder, Jr., or Robert Foster
Virginia State Facilitator
Educational Services, Inc.
P.O. Box 562
Richmond, VA 23204
(803) 536-5932 or (804) 732-3584

WASHINGTON
Keith Wright
Washington State Facilitator
Yakima Public Schools
104 North Fourth Avenue
Yakima, WA 98902
(509) 575-3234

WEST VIRGINIA
Kenny J. Smith
West Virginia State Facilitator
P.O. Box 1907
Elkins, WV 26241
(304) 636-6918

WISCONSIN
George R. Glasrud
Wisconsin State Facilitator
Department of Public Instruction
Instructional Services Division
125 South Webster
Madison, WI 53702

VIRGIN ISLANDS
Phyllis Betz
Virgin Islands State Facilitator
Virgin Islands Department of Education
P.O. Box 630
St. Thomas, VI 00801
(809) 774-0807

HOW THE SLOAN FOUNDATION'S SCIENCE EDUCATION PROGRAMS ARE CREATED, MANAGED, AND MONITORED

Kenneth A. Klivington
Alfred P. Sloan Foundation
New York, New York 10111

As Program Officer and Administrator of the Alfred P. Sloan Foundation Research Fellowships, Dr. Kenneth A. Klivington is deeply involved in scientific affairs. His experience in science, as opposed to his present administrative connection, has been principally in neurophysiology, psychology, and information and control, but has also included the use of computers in architecture and urban planning, and, as a research engineer, radar interferometry, laser optics and infrared telescope design. He holds the B.Sc. degree from M.I.T., his master's from Columbia University, and the Ph.D. from Yale University in engineering and applied science.

When asked to make a presentation of this sort, I find, as I'm sure everyone does, that my perception of the world changes. The subject begins to ferment subconciously and alters the way I think about things. So with the invitation to tell this group something useful and interesting about the Sloan Foundation, science education began to bubble in the back of my mind.

Prior to the invitation, I had read the December 27 issue of the British news magazine, The Economist, which contained an article about seven men who had contributed the most fruitful ideas in science and technology since the war. Among the men and discoveries were James Watson with DNA and William Shockley with the transistor. After the invitation had set the science education stew bubbling on the back burner of my mind, something floated to the surface. It was the interesting fact that more than one of these men recalled nearly blowing himself to pieces while fooling with a chemistry set as a child. Now I, too, recall doing the same sort of thing when I was about 10 years old. That doesn't put me in the same league by any means, but it did make me reflect a bit on what gets young people involved in science.

I bought my son a chemistry set a few years ago when he was 10. It had been a long time since I looked inside the cover of a kid's chemistry set. I was shocked. Virtually all of the "interesting" chemicals had been expurgated. It was, in fact, quite impossible for my son to blow up anything. The most dangerous ingredient in that chemistry set was a candle. So after making some ammonium chloride smoke and changing the colors of a few solutions, he put the cover back on the chemistry set and it now gathers dust on the shelf.

I suppose I should be grateful that my son has been prevented from blowing himself up by regulations that cover the contents of chemistry sets for kids. Yes, of course it's still too early to tell whether my son will become a scientist or a fireman. There are certainly more factors than chemistry sets that affect that decision. But all the same, I wonder how many other factors in addition to chemistry sets have been regulated out of the equation. I don't mean to imply that chemistry sets should not be regulated, nor that there should be no government regulations at all. What I do want to point out is that we are only beginning to uncover some of the hidden costs of regulation. Those of us concerned with science education should not overlook those subtle effects.

The Alfred P. Sloan Foundation

Regulation is indeed one of the concerns of the Sloan Foundation, which recently funded a study of the effects of Federal regulation on higher education.* It is not, however, the concern at the top of my agenda today. To introduce that agenda, I expect it would be useful for me to give a brief introduction to the Sloan Foundation so you'll have some idea of the context for the other things I want to talk about.

Alfred P. Sloan, Jr., was a major figure in the automobile industry. It was he, in fact, who put a small manufacturing company on the map. You know it today as General Motors. So in an indirect way, the Sloan Foundation is the General Motors foundation. Apart from the existence of General Motors, perhaps the most profound effect of Mr. Sloan's years as its head is the custom of changing car models annually.

In 1934 Mr. Sloan created a charitable foundation intended to foster education in economics. Its major activity at the time was support of movies, radio programs, and pamphlets to educate the public about the private enterprise system. Technology slowly crept into the picture, largely through support for various activities at Mr. Sloan's alma mater, the Massachusetts Institute of Technology. By the 1950s, Mr. Sloan became persuaded, along with a great many other influential people, that support for the scientific underpinnings of technology was essential for the good of the country. On the recommendation of a special advisory group of scientists, a new program designed to support basic research was initiated by the Foundation. It provided flexible research support to especially promising young scientists in the fields of physics, chemistry, and mathematics. That program is generally acknowledged to be one of the Foundation's most successful activities. It continues today and has been broadened to include neuroscience, economics, and applied mathematics.

* A Program for Renewed Partnership: The Report of the Sloan Commission on Government and Higher Education. Ballinger, Cambridge, MA, 1980

By 1980, science accounted for about one-third of the Foundation's regular grant expenditures of roughly $15 million per year. Of that, $1.75 million was in fellowships for basic research and over $3 million for research and training in cognitive science, a program I'll discuss in some detail later. The remainder went for support of miscellaneous programs and projects in science.

For the record, other Foundation activities include support of research and higher education in economics, technology, and administration.

The College Science Program

Focusing now on the theme of creating, managing, and monitoring science education programs, I'll first discuss a program that the Foundation created back in the 1960s to help improve science education in private liberal arts colleges. Although most of this is history, that very aspect offers the advantage of being able to follow the development of a program over an extended period of time. The procedures followed in that development remain typical of the way the Foundation operates today. As you'll see, too, many of the problems the program was designed to address have returned to haunt us again today.

Back in 1962, the Foundation received a proposal from a leading undergraduate institution with a remarkable record of producing graduates who went on to eminence in various fields of science. But a threat of unknown proportions menaced the college's reputation. The cost of research had risen beyond the means of such institutions. If faculty research could not be supported, the college could not keep its outstanding science faculty. The implications for science education were clear, so the administration called for help.

Now and then it happens that a proposal which comes unsolicited through the door of the Foundation carries implications far broader than the immediate problems of the suppliant. In this case, it was clear to the staff of the foundation that if this particular liberal arts college was in trouble in its science education program, others were probably in deeper trouble. Was there a real threat that the liberal arts colleges would cease to be a source of graduate students for major university science departments? What are the implications of having only university colleges as the source of graduate students in science? The liberal arts colleges attract a different sort of student from those at the university colleges. Would loss of the liberal arts students to science in some undefinable way impoverish pure research?

All of these question and issues became the subject of intense staff discussion during 1963. By mid-year, it was decided that in principle the Foundation would provide some sort of support to a select group of liberal arts college science programs, but the broad purpose of the program remained a subject of dispute. The choice was between two alternate approaches. On one hand the Foundation might try to sustain or possibly augment the flow of able young men and women from liberal arts colleges into the graduate science departments of major universities. The alternative was to attempt to help maintain and improve the quality of science education in liberal arts colleges for both scientists and non-scientists alike.

The first approach implied that only those institutions which were already strong in science would be targeted for support. If the purpose were to improve science education in liberal arts colleges as a whole, institutions weak in science but strong overall might also be reasonable candidates for support. Taking the first path would mean making a small number of relatively large grants, the second a somewhat larger number of small grants.

In the end, the Foundation opted to have the best of both worlds. The objectives of the program formulated in 1966 were (1) to ensure a continuing supply of science graduate students from the liberal arts colleges; (2) to improve the quality of secondary school science teachers, traditionally the products of liberal arts colleges; and (3) to promote scientific literacy among non-science majors. Assistance was to be primarily for needs unique to liberal arts colleges. First on the list was the capacity to attract and retain bright young science faculty, so faculty development, including research support, had top priority. Some funds were intended for equipment and facilities. The Foundation also encouraged collaboration with universities to augment the colleges' science resources.

The College Science Program raised a common problem for foundations. It is clear that the Sloan Foundation alone cannot possibly help every eligible institution. What the staff people must do is to be optimistic in the extreme and hope that Foundation support will produce models of success (a not unreasonable hope) so that other institutions will be able to imitate these models with funds from other sources (the wishful part). At any rate, in order to try to meet the goals it had set forth, the Foundation sent invitations to three groups of institutions. The first was made up of strong, science-oriented liberal arts colleges; the second, colleges of limited strength in science but with a clear determination to change that situation; the third, colleges strong in arts and letters, but lacking distinction in science. Thirty-five colleges, roughly evenly divided among the three categories, received letters of invitation. The Foundation planned to divide $7.5 million among 15 to 20 of them over a 3- to 5-year period.

While the institutions were formulating their proposals, members of the staff visited them to assess the likely degree of institutional commitment. Without firm commitment to the purposes of the program, including continuing support beyond the period of a Sloan grant, an institution could not be expected to show more than a transient change in the quality of its science program. After the visits, the Foundation assembled a review panel of distinguished scientists to help in the final selection process. By December of 1966, 20 notification telegrams were sent out to the winners.

All of this was not going on in a vacuum, of course. The liberal arts colleges found themselves facing an ever-growing financial squeeze and exerted considerable force on other sources of funds as well as the Sloan Foundation. By mid-1966 both the National Science Foundation (NSF) and the Research Corporation indicated their intention to provide funding similar to that under consideration by the Sloan Foundation. NSF intended to begin its College Science Improvement Program (COSIP) on a modest scale. Of course something modest for NSF is still often much larger than what the Sloan Foundation can put on the line, but because NSF money was distributed more broadly than the Sloan dollars, individual grants generally turned out to be smaller than the Sloan grants. Fourteen of the 149 COSIP institutions were on the Sloan list, and seven on that list also received Research Corporation support.

By 1972, when the College Science Program grants were running out, the world had changed. Science was no longer growing. COSIP had peaked at $9 million a year and was winding down. The Research Corporation had returned to individual research grants. Students regarded science as a threat rather than a savior. They perceived, too, the glut of science Ph.D.'s. Admittedly, the growth in pre-medical students exerted some positive influence. So too did the concern for "ecology" and "the environment." But the overall effect of all these confounding variables was to make it especially difficult for the Foundation to evaluate the success of its College Science Program and decide where to go from there.

As a start, Foundation staff visited all 20 institutions and talked as well with NSF staff and staff members of the Research Corporation. Copious files of reports and memoranda also had to be reviewed in an effort to learn what had been accomplished, which approaches succeeded and which failed.

Of the six colleges in Group I, those already strong in science, five performed satisfactorily, one outstandingly. All added new faculty and stimulated student and faculty research. But with Sloan support about to terminate while COSIP and Research Corporation dollars ceased to flow, all expected to have to cut back significantly, despite earlier intentions to carry on their expanded programs after grant termination.

Not all colleges in Group II could claim success. Five of the seven did indeed make significant improvements in their science education. One showed little improvement, citing individual gains to faculty in terms of equipment, travel, etc., at the expense of any concerted institutional effort. The seventh embarked on an ambitious curriculum development program, but later decided to abandon it.

Of the five successful programs, all notable for increased science faculty size and enhanced research opportunities, two seemed likely to be able to maintain their momentum. For the others, budgetary problems posed a serious threat.

Group III offered mixed performances. Four of the seven colleges were successful in building some science capability to fill the previous vacuum, three by adding faculty or teaching interns, one by investing in equipment. Three turned in disappointing performances, in one case because of the loss of leadership.

On the basis of this kind of college-by-college assessment, with 15 at least satisfactory performers out of 20 grantees, the results of the College Science Program look good. In fact, this program, like many of the activities of a general purpose foundation, involved a rather high degree of risk. Colleges were allowed considerable flexibility in the use of funds and were called upon to exercise a high degree of initiative. Given the risks, the statistics look good.

But in a program of this sort, it's necessary to back away from the trees to see the forest. The College Science Program was a family of grants with a common purpose--to enhance the quality of science teaching in three groups of colleges, each group being only a small sample of a much larger group of liberal arts colleges. Taking the program as a whole, there are three results which the Foundation would expect to find in order to consider the program a success: (1) some significant portion of the colleges would in fact improve the quality of their presentation of science by some reasonable measure; (2) the colleges would be able to maintain this enhanced quality out of their own resources or out of resources that the new level would attract; and (3) the accumulated experience gained in the process of improvement would to some extent guide other liberal arts colleges toward a similar improvement. These criteria provide a measure of success that is more meaningful than the college-by-college assessment.

On the first score, 15 of 20 colleges did indeed enhance some aspect of their presentation of science. But the failures offer lessons perhaps more important than those of the successes. Three of the five poor performers stumbled because of lack of leadership. Lack of effective guidance in one of these seems to have led to an inability to develop a coherent plan of action. Another lost a dedicated president during the first year of the program, and subsequent administration was not strong. In the third, there was no coordinated control of the program. These failures of leadership were all in the lower two categories of institutions--two in the group with no previous claim to strength in science. There are no surprises here. The Program was an experiment--a test to see if an institution could come up with required leadership. Experiments must sometimes lead to failures, as they did here when a college failed the leadership test:

Two of the five unsuccessful colleges conducted experiments in radical curriculum reform. For us, at least, this lesson underlined the dangers of interdisciplinary curricula at the undergraduate level. There are compelling arguments that all science is one and that it follows that it all should be taught as one. On the basis of this experience, however, it appears necessary to teach the distinctive central concepts of each of the disciplines of physics, chemistry, mathematics, and biology before it becomes possible to teach at sufficiently profound levels of science for the interconnections among disciplines to appear.

When it came to the questions of sustaining the new level of their programs, we found that all of the institutions were in trouble to some degree. No one, of course, could have foreseen the troubles of 1972 back in 1966. Indeed, the absence of an effective crystal ball is a persistent problem for all private foundations like Sloan, which provide support for building new or expanded institutional programs that must eventually be supported on a sustaining basis from other sources.

Finally, on the score of accumulated experience which might help guide other colleges in a more effective improvement of their own science programs, a few lessons were learned:

(1) Stimulation of on-campus research, particularly research with student participation, greatly enhanced the teaching and learning processes.

(2) Postdoctoral short-term residents on campus can be highly stimulating to the student body and can themselves have a a rewarding experience. (Regrettably, support for this type of visitor was most profoundly affected by termination of Sloan support.)

(3) Provision of faculty research funds and the presence of postdoctoral fellows on campus had an important evaluationary effect on curriculum. Experiments in revolutionary reform left no lasting mark.

(4) One of the goals set by the Foundation was improved college-university linkages. No college displayed sufficient initiative to effect any such improvement. The notion that such linkages are in the self-interest of the college will have to be re-examined and, if verified, new ways to encourage their formation invented.

The Final Stage

The lessons learned from the College Science Program appear to be valuable, but they are of little use in the absence of funds. The evaluation of the Program had been a useful and instructive exercise, but it was, in a sense, a disappointing one, despite the relatively successful expenditure of funds. It led the Foundation to begin to rethink its role in science and science education. In 1973, the Foundation decided to award grants totaling about $1 million to 14 of the original institutions to help them consolidate the gains made under the earlier grants and continue their efforts to assemble sustaining support. But there was not a great deal of optimism on either side that this added support would do more than forestall the inevitable.

There has been no formal review since these grants were awarded, other than that provided by annual reports, to assess the current state of science education at either the participating colleges or other institutions. No one, however, will question that science education is not in good health. And not just at the liberal arts colleges. It is also true that many of the problems today are exactly those that the Foundation defined in the mid-1960s when the College Science Program was being conceived. At the moment, the Foundation has not identified any attack on those problems which makes sense for an institution of its size. Clearly, the success of any such attack depends on the presence of continuing support for continuation and expansion of successful efforts upon demonstration of their success. An important lesson for any private foundation is that it is all but impossible to predict the presence of that support. This is a lesson that is learned in more than one way. It helps to hedge your bets, of course, but we've slipped even on an apparent sure thing.

Neuroscience

During the latter part of the 1960s, the Sloan Foundation was concerned about its future role in science. It was clear by then that Federal support for science was far in excess of what Sloan or any other private foundation could muster. Was there a role for private dollars in science? Could they do anything Federal dollars could not?

A committee of distinguished scientists was assembled to address these and related questions. They came up with a list of recommendations which identified a number of relatively small but increasingly important areas of science which for one reason or another were not in a position to attract much Federal support but which could be aided substantially by a modest amount of money. One of them was called "behavioral biology," an area which eventually became better known by the name of "neuroscience."

In 1969, the Foundation initiated a new operational policy by creating the concept of the Particular Program. In contrast to the passive activity of the so-called General Program, which deals primarily with unsolicited proposals in the Foundation's general areas of interest, the Particular Programs take a more active approach. They are intended to identify a particular problem or opportunity the Foundation might hope to address effectively with a finite budget over a finite period of time. The original guidelines called for $10-15 million over a 5- to 7-year period, but inflation is likely to push up the dollar figure. One of the first of the Particular Programs was in neuroscience.

In 1969, neuroscience was an embryonic field whose practitioners were concerned with understanding the structure and function of the nervous system and its role in behavior at levels ranging from the molecular to the ethological. When the Program began, there were no more than a handful of academic programs in neuroscience. Following a 7-year investment of some $12 million, there are now over 500 programs and a professional Society for Neuroscience with about 5,000 members. The Sloan Foundation alone was not responsible for all of this, of course. Neuroscience was a field whose time had clearly come, and the Foundation had latched on to a nearly sure thing. But once again, there was that lesson to be learned.

Most of the support that went into the field from Sloan went for the development of broadly interdisciplinary research and training programs. This was done at a time when support for science was generally shrinking, so the growth of neuroscience had to take place in most institutions at the expense of something else. It wasn't hard to guess that most major institutions were eventually going to need a neuroscience program of one sort or another. But once again, as in the case of the College Science Program, it was hard to guess what the general support picture was going to look like at the end of the period of Sloan support, except, of course, to guess that it was going to look worse than expected. And it did. Neuroscience was still a growth area at a time of cutbacks and neuroscientists probably fared as well if not better than anyone else in getting a piece of the reduced Federal research dollar. While it is true that by 1976 the market for neuroscience Ph.D.'s was better than that in most fields, many of the programs that had grown up under Sloan support found that they were too big to sustain themselves with the number of trainees and junior faculty they had built up over the years. So once again, the Foundation found that its best laid plans did not completely match the future they had predicted. Several institutions required unforeseen additional support to provide them with much needed time to scale down to a more realistic level. I'm happy to say, however, that virtually all of these programs are still alive and well. Rather than say more about them, however, I'll go on to a subject of more direct relevance to the interests of this audience.

Cognitive Science

As the Particular Program in Neuroscience neared the end of its lifetime, the Foundation began an exploration for another area of science where it might hope to be as effective as it had been in neuroscience. Early explorations took the form of informal conversations between Foundation staff and eminent scientists from every conceivable discipline. They were asked what special contribution the

Foundation might make to the advancement of science over the next 5- to 7-year period with an investment of $10-15 million. Now, it is surprising how altruistic most scientists can be when asked such a question. Few gave the selfish answer, "Put it all into my discipline." And, while there was no clear consensus, there was exceptionally frequent reference to imminent advances in research concerned with understanding cognitive processes. The same references recurred in letters written by distinguished scientists from around the world who were asked the same question by mail. Many of them pointed to the apparent convergence of work going on in many fields, including computer science, linguistics, and psychology, which were concerned with such matters as speech comprehension, pattern recognition, and the acquisition of language. With these suggestions came warnings that much of this work was less than first-rate and that the apparent convergence may be no more than superficial.

These conclusions are now much easier to draw than they were at the time. We were then proceeding with considerable caution, aware that we might be hot on the trail of a wild goose. The next step was to assemble, again informally, small groups of scientists working in the still vaguely defined area of cognition, but coming from a standard discipline where they enjoyed an excellent reputation. Could they concur that something was happening--or about to happen--that would elevate the study of cognition to new levels? The answer was an unqualified maybe.

At the same time, we wrote to a large group on investigators of similar reputation asking them if they thought there was, or was about to be, a field of cognitive science, and if so, what it might look like. We received generally positive responses, a wide variety of maps of the putative field, and many cautionary notes, both explicit and implicit. Something was clearly in the wind, but no one could define exactly what it was. More discussions appeared in order. There followed two round table discussions, one on the East Coast and one on the West. Each brought together a group of philosophers, linguists, computer scientists, psychologists, and other cognitive types to consider the reality or unreality of cognitive science. The East Coast meeting made it clear that if there is a field, it is fraught with controversy. The West Coast meeting, while not without controversy, demonstrated that it is possible to establish some consensus as to what the goals of cognitive science might be and to initiate some cross-disciplinary dialogue about how to achieve those goals.

With a mixture of optimism and caution, the Foundation staff formulated plans for a Particular Program in Cognitive Science. There were to be three phases, with ongoing review and the possibility of terminating the program to be considered at each juncture. Phase I would involve a widely distributed series of modest grants for exploratory purposes, largely workshops and visiting scientists. These would attempt to determine whether fruitful cross-disciplinary collaboration leading to new research approaches could be established. Phase II would build on these interactions to train postdoctoral investigators with a background in one discipline, such as cognitive psychology, to work on problems in another area such as artificial intelligence. Training at the postdoctoral level was considered to be the most rapid way of creating productive researchers who could be considered to be true cognitive scientists. Finally, Phase III would focus on a few of the most successful programs and provide institutional development support intended to produce an enduring cognitive science research and training program at each institution.

All of these plans and the ongoing monitoring of the program are conducted with the aid of a Cognitive Science Advisory Committee which is composed of scientists distinguished for their administrative and scientific wisdom, but not necessarily possessing any credentials in any aspect of cognitive science. Their periodic review of progress and reformulation of operational procedures have proved invaluable in guiding the course of the program.

Phase I proved more of a success than anyone could have hoped. Each of the 14 participating programs developed a strong and effective multidisciplinary core group which rapidly opened a variety of new lines of research. Many groups shared common interests, but each developed a unique approach to the field. Controversy remained a dominant characteristic of the program, but many opponents to the principle of the program changed their minds after spending some time at one of the participating institutions.

When it came time to decide on Phase II, it was clear that it was appropriate to go ahead; the intellectual excitement was clearly infectious. But there was obviously going to be a problem in narrowing the number of institutions participating in the postdoctoral training activities. Not one program had fallen on its face--a clear possibility in this murky and uncertain territory. And it was certainly too early to weigh the relative success of one program against another with so many diverse activities going on. The Foundation decided to make it possible for [illegible] the participating institutions to take part in Phase II if each could produce a persuasive proposal. So far each has.

Now plans are being laid for Phase III--institutional development. And we face once again the problem of determining what the likelihood of sustaining support will be about 7 years from now. The original notion had been to narrow Phase III support to two or three institutions. With an anticipated $10-12 million to be divided among them, the sense is that such figures would build unbearably large programs. There is also a sense that, given the great diversity of the field and its relative youth, it is not yet possible to decide on the most potentially fruitful approach. The number of awards now under discussion is four or five.

The Future

What will the Sloan Foundation be doing in the years ahead to help support research and teaching in science? In all likelihood Phase III of the Particular Program in Cognitive Science will run its course. The years should help map more clearly what is still an intellectual territory shrouded in fog. Many of us expect that major advances in teaching and learning are going to result from basic research in cognitive science, but we won't know for some years yet. Since its earliest involvement with science, the Foundation has taken the position that immediate payoff or the hope of immediate payoff plays no role in its support of basic research. I expect that the program of Sloan Research Fellowships on which this tradition is founded will continue and perhaps expand. It remains one of the Foundation's most respected programs.

As for new ventures in science or science education, they remain far more uncertain. Perhaps a new opportunity like neuroscience or cognitive science will be found. Perhaps someone will shed new wisdom on the problems which the College Science Program hoped to solve. But for the moment, and in a different way, the continuing vicissitudes of Federal support for science and science education stymie those of us in private foundations who are concerned over how best to deploy the relatively modest but undoubtedly valuable resources that are available to help build for the future.

THE INTERPENETRATION OF RESEARCH AND DEVELOPMENT IN SCIENCE EDUCATION

Rustum Roy
Materials Research Laboratory
The Pennsylvania State University
Universiy Park, PA 16802

Dr. Rustum Roy received his early education in India and came to the United States for his doctoral studies at the Pennsylvania State University in the field of ceramics. He has continued at that university to the present and is now Professor of Geochemistry and Solid State. He has also been Director of the Materials Research Laboratory and Chairman of the Science, Technology and Society Program from the 1960's to the present. Dr. Roy is a member of the National Academy of Engineering and an officer of many professional societies. He has founded or edited at least eight journals and bulletins, and written over 300 scientific papers as well as several books. As a tribute to his many contributions his colleagues at Cambridge University have named a mineral after him.

The purpose of this session is to reinforce by illustration and reasoning what is obvious to almost every practitioner, namely, that research and development in science education are simply labels on a continuum of change. The four speakers will each demonstrate how this interpenetration of research and development affects their own practice. My task in these very brief introductory remarks is to present my overview of the relation between these activities. I wish to make three points:

1. <u>Research and development are two links on a continuum.</u>

The first figure illustrates the total chain of activities involved in technological innovation of any kind. This schema comes from the world of technological research and development, and I have superimposed on it the terminology of <u>R</u>esearch, <u>D</u>evelopment, <u>D</u>issemination, and <u>U</u>se (RDDU) commonly used in science education circles.

The two arrows are important. The one that starts on the left represents the <u>push</u> of discovery or invention as responsible for triggering progress down the chain. The arrow that starts on the bottom right represents innovation driven by the <u>pull</u> of societal need. I have coined the terms "telestic" and "atelestic" for these two kinds of basic research.

The point to be made from this figure is that except in very rare instances--and these can hardly appear in research in science education--there is very little atelestic research which makes an impact. Certainly in science education, research and development are both telestic, i.e., they are need-driven with some educational goal in view.

2. <u>All research in science education is "applied" science research.</u>

This is the second point to be made from Figure 1. In the minds of many, basic telestic science <u>is</u> applied science and not "basic science." While many would regard all this as semantic quibble, it is far from that. The fact that the great American academic dream machine does not recognize the existence or validity of applied science in a university constitutes a major problem. Yet perhaps the greatest distinctive successes of the quintessentially American university establishment is the Agricultural Experiment Station which is almost the prototype of applied research. It was a complete system of "RDD and U" and that is what is needed for science education--a Science Education Experiment Station attached to each land grant or other institution.

3. <u>Innovation + Impact are mixed in only slightly different proportions in RISE and DISE.</u>

I turn now to my Figure 2, which shows the relation of innovation to impact as we go across the chain. This is an attempt to show that in the science education area we operate in the middle of the continuum as any applied science would. The bars show the RISE programs have a certain component of innovation, but they must also clearly demonstrate their putative impact. In the DISE programs the mix is somewhat richer in the impact component. Moreover, the third direction of time is shown as a third axis moving back out of the plane of the paper. The slope of the lines with time is clearly towards more impact. In other words, both RISE and DISE must move toward having a measurable effect on the educational system. Given this situation--and these are merely a representation of the facts--it is clearly a moot point that research and development in science can ever be separated conceptually and functionally. They will obviously draw upon each other iteratively as much as the science of thermodynamics drew on the technology of the steam engine and vice versa.

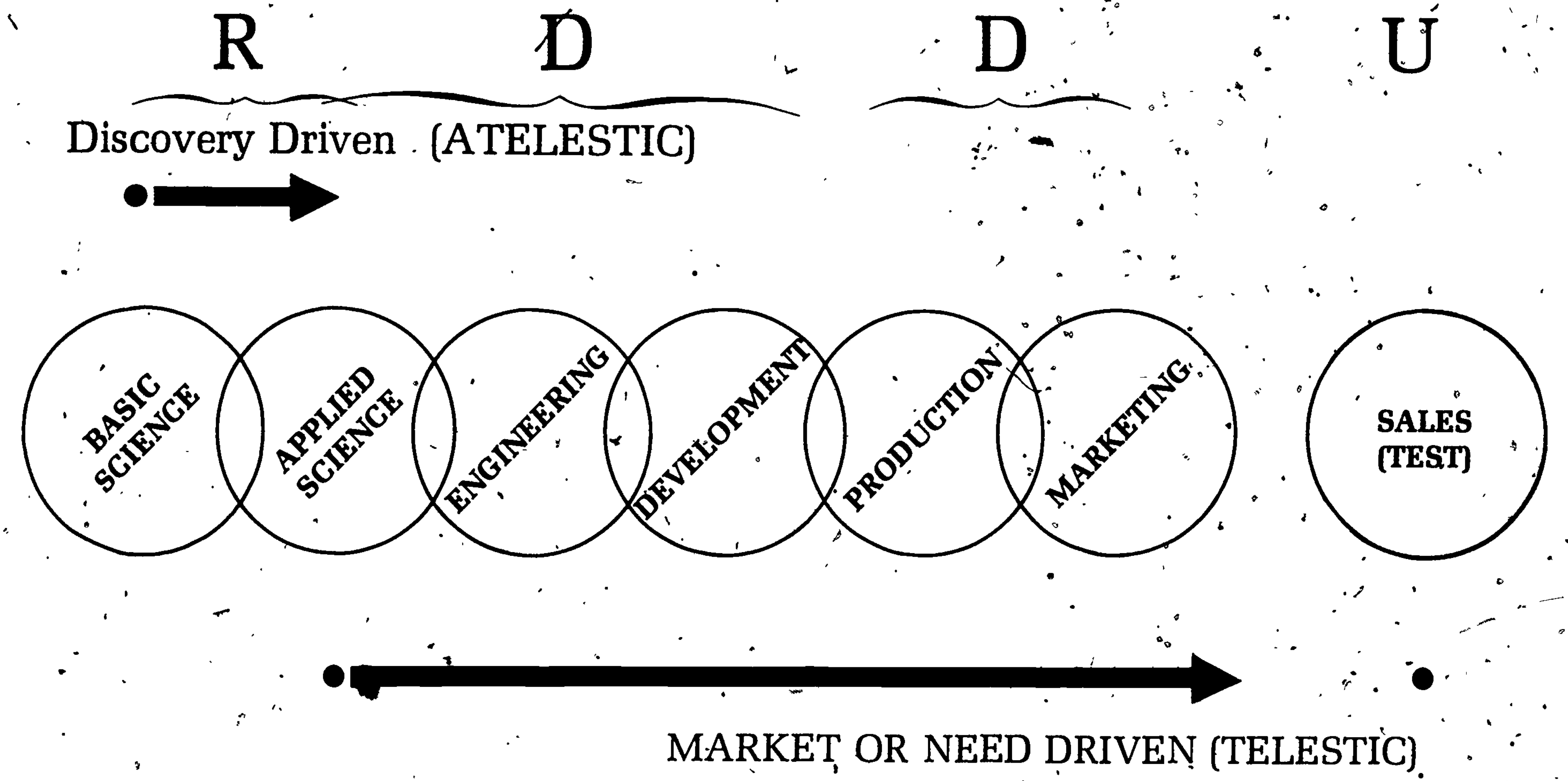
R
D
D
U
Discovery Driven (ATELESTIC)
BASIC SCIENCE
APPLIED SCIENCE
ENGINEERING
DEVELOPMENT
PRODUCTION
MARKETING
SALES (TEST)
MARKET OR NEED DRIVEN (TELESTIC)

FIGURE 1

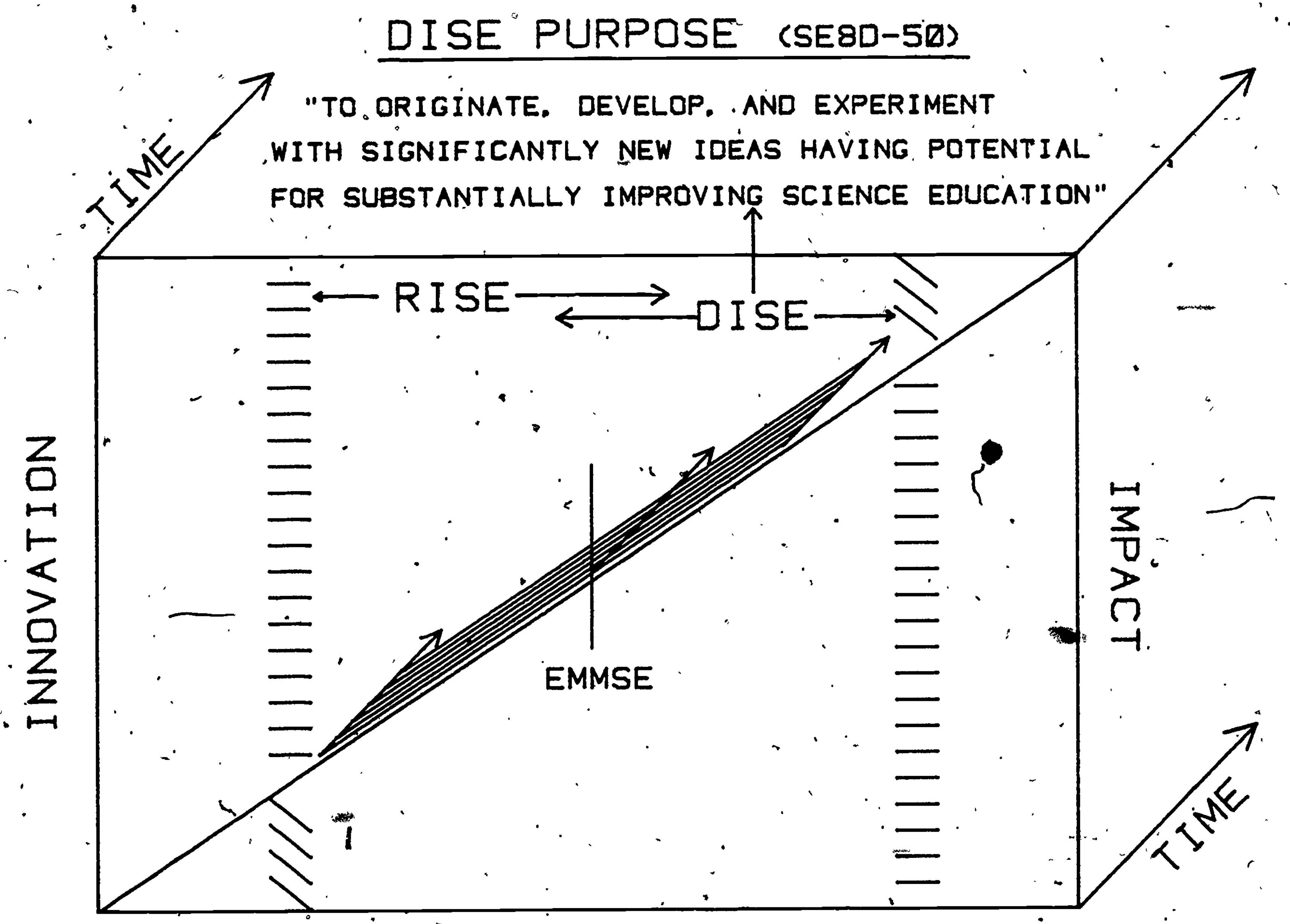

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FIGURE 2. ILLUSTRATION OF THE MIXTURE OF INNOVATION AND IMPACT IN DISE PROJECTS AND THE NECESSITY OF INCREASING IMPACT WITH TIME.

R&D INTERPLAY IN PROJECT PHYSNET

Peter Signell
Michigan State University
Department of Physics
East Lansing, MI 48824

Professor Signell received his B.S. degree from Antioch College and his Ph.D. from the University of Rochester. He taught at Bucknell University and Pennsylvania State University and has been a Professor of Physics at Michigan State University for the past fifteen years. Professor Signell has published over sixty papers, mostly on properties of the nuclear force. He has delivered a number of invited papers at conferences on both physics and physics instruction and has supervised ten Ph.D. theses. He has been a Visiting Staff Member at the Los Alamos Scientific Laboratory for some fourteen years, is a member of the National Academy of Sciences Numerical Data Advisory Board and Chairman of its Education Panel, and is on the NSF/DOE Nuclear Science Advisory Committee on Computational Capabilities for Nuclear Theory. He is on the National Advisory Committees of the NSF/SEDR Materials Science (EMMSE) and Solar Technology projects. His instructional research and development projects have been supported by the Alfred P. Solan Foundation and the NSF.

My assignment is to describe the interplay of research and development occurring in a typical development project, namely, the one for which I am project director. I will describe that interplay as I see it, then tell you a little about our ideas for enlarging it.

There are three fields of research where findings have proved useful to us: communication, science education, and cognitive and social psychology. (In communication we include linguistics, typoggraphy, and graphics.) Such research results are being applied by us in order to choose appropriate media for specific messages, to design the organization of material within a medium, and to improve learners' motivation at the same time that we work on their science-learning and problem-solving skills. Recent technological developments also play a critical role in our project, but they will not be described here.

First, let me briefly describe our project. The project's main goal is to produce a system of instructional physics modules for independent study. The target audience includes college students majoring in the sciences and engineering, practicing professionals in industry and government, and bright science-oriented high school students. The instructional modules are mostly in print form and are 7-14 pages long. They are meant to be about the length of regular lectures. The authors are physicist/teachers scattered around the country who contribute their manuscripts in a manner analogous to the way research papers are contributed to journals. The modules are also available from electronic storage.

Each module is documented in such a way that it can easily serve as a node in various learning sequences. Learners, individually or in groups, follow what look like road maps to get from where they are (intellectually) to where they wish or need to be. On these maps, cities' locations are occupied by modules. Just as a city will usually serve as a way station for people who are passing through it in different directions, in similar fashion a module will usually be taken by various learners traveling along different paths that only temporarily cross or merge.

We find students pursuing several different path strategies. Some individuals go along minimum paths to reach preset personal and professional goals. Other individuals enjoy taking interesting side trips. The side trips sometimes result in changes of major! Also, some individuals report more satisfaction from studying a subject in some depth before being rushed on to the next subject. This feeling is widespread among professionals.

Some faculty members have objected that students would find a multipath system too confusing. We find that if we give students the map, a colored felt tip marker, and printed directions and restrictions, they have little trouble marking out appropriate paths on the map. After all, most students are quite used to plotting their way on road maps. Several thousand students have successfully marked and followed their physics maps by now.

There is one additional facet which I would like to describe: that of overviews. Suppose that you, as a learner, are steering your course through our network of paths. Think of it as traveling along on the surface of the earth. Now suppose that you can also rise from the earth's surface to obtain an overview of the surrounding terrain. Suppose you can rise to consecutively higher levels, obtaining an ever more global view. Such hierarchical levels of overview are provided in the module system by special overview modules. This overview function is graphically reinforced by the map and by the format of the modules' tables of contents. Indeed, with the map, the overviews, and the tables of contents, the learner is provided with a hierarchical structure of knowledge for the territory being covered. As we make the modules smaller, hence more numerous, more of the structure of the subject will be exposed to view.

Research has played a vital role in shaping the module system I have just described. First, some very nice work has shown that college-age students are most likely to be strongly motivated if they can see a total path linking present decisions to the achievement of personal goals in the future. Such a path should include a number of steps along the way, and the student should receive reinforcement as the path is being traversed, reinforcement that builds credibility for the whole path.

In our case, the students find that each module-to-module link on the map is indeed necessary, and this helps build that credibility.

Each link on our map represents a prerequisite relationship between the two modules at opposite ends of the link. That is, the module at one end of the link provides a skill which is a prerequisite for the module at the other end of the link. A module's prerequisite skills are explicitly stated in the module, in a self-testing or pre-test format. They may involve knowledge, rule application, problem solving, estimation, evaluation, etc.

A module's author is the one who constructs the module's list of prerequisite skills. For each prerequisite skill, the author also lists those modules in the system which adequately provide that skill. A module's list of prerequisite skill modules is all we need to place the module on the map and draw in its links.

Recent results in cognitive psychology, involving the direct study of physics problem solving, have suggested the importance of developing mini-skills, then clustering them on various levels to form a hierarchy. By making the hierarchy explicit, the brain has a structure upon which to hang the chunks as they are met, resulting in much more efficient learning. It then can use the words, visuals, and relations in the hierarchy to design a "top-down" solution to any particular problem.

The hierarchy is made explicit through the overview modules and through each module's hierarchical Table of Contents. The professional's words and word associations are made explicity through each module's "input vocabulary" and "output vocabulary" lists, plus their expansive Glossaries. Some crude network-type relationships are made explicit via the module's Prerequisite Network Diagram.

Some research findings that are often quoted in our project are those that confirm high school English teachers' rules for good written English. The most important of these rules delineates the position and design of a paragraph's topic sentence. Our physicist/authors tend to define all word concepts first, then combine them into a topic sentence. The trouble is that the topic sentence then occurs at the end of the paragraph, and the topic paragraph occurs at the end of the module. A bold suggestion to the author to rearrange the material usually results in much bad noise. However, data from "topic sentence" research is more respected and is usually enough to send the author back to the drawing board. Upon completion of the revision, the author is pleasantly surprised to find that the research findings check out personally: the revised version seems significantly better.

Another well-quoted research result is that on "chunking." This research says that the human brain likes no more than approximately five to seven new chunks of knowledge at a time, plus one chunk that ties the others together. Thus most modules have a two-level hierarchical layout of their tables of contents, with no more than approximately five paragraph titles per section, and no more than approximately five sections per module. The modules, in turn, are grouped in blocks of no more than five.

Apart from the basic research applications I have been discussing, we also have to include applications from research into the author's attitude or stance, the strengthening of recall, and the needs of industry for increased productivity. Research in typography influences our printed line length, line spacing, choice of type faces, and right margin justification (or lack of it). From research on graphics we use results relevant to left-right symmetry, the degree of detail in figures, figure labels, and captions.

Finally, there are recent research results suggesting that even experienced physicists have gaps in their problem-solving knowledge, gaps that could be remedied by raising physicists' most general concepts to a higher level in the hierarchy. Another way of saying it is that we often neglect teaching the most general physics because we want students to use simple algebraic manipulations. Unfortunately, the simple approximate formulations are frequently all that stick in the learners' long-term memories. Our project is now going back through already-produced modules, making it clear that many of the exact-looking equations are mere approximations. At the same time, we are inserting at least a paragraph describing the problem's general method of attack. With new modules we are also trying to make sure that the learner obtains a feel for the real-life circumstances under which the beautiful little approximate formulas are useful.

Have we influenced any researchers? We think so, especially in the case of an investigation into the relative effectiveness of various models of the tryout-revision cycle. After a great deal of discussion, we think we have persuaded the researchers to compare those tryout-revision models which might reasonably be used by developers and practitioners. In return, the researcher will gain access to the tryout-revision data being systematically collected by the project.

We have recently made a modest first step toward linking together developers and practitioners. Initially, the practitioners involved are mainly high school teachers who do not have enough talented and eager advanced physics students to justify a special class. Nevertheless, they find that they can offer our college courses, using our modular materials, in various independent study modes.

To help them along and to get feedback, we are in daily contact with them via computer conferencing and electronic mail. This means that each person in the network can dial in via a local telephone number when there is a need or when time is available. Yesterday in my hotel room I dialed the local TELENET number here in Washington, D.C., connected to the Michigan Computer Network, and responded to messages that included one from our module distribution person, one from a high school teacher in Portage, Michigan, and one from a woman in New Hampshire asking for consultation on a homework problem in theoretical mechanics.

As our network of developers and practitioners expands, we hope that a number of researchers will join us. We want them to work with us on applications of their research results, for inspired application is just as hard to come by as inspired research.

I see no end to applicable results coming from research in science education and related areas: This field appears to be in its infancy and is being constantly challenged by the appearance of new technologies. As researchers, developers, and practitioners become more closely coupled, modules will continually change in response to new insights. At that point, science education research and development will be most like research and development in the natural sciences and will have the same apparently limitless horizon.

A COMPREHENSIVE PROGRAM IN PHYSICS EDUCATION: RESEARCH, CURRICULUM DEVELOPMENT, AND INSTRUCTION*

Lillian C. McDermott
Physics Education Group
Department of Physics
University of Washington
Seattle, Washington 98195

Dr. Lillian C. McDermott, a graduate of Vassar, received her Master's and Ph.D. degrees in Physics from Columbia University. She is presently a Professor of Physics at the University of Washington. Dr. McDermott also heads the Physics Education Group made up of physics faculty, visiting faculty research and academic associates, and doctoral candidates doing their research in physics education. Among the students in the Physics Education Group are minority students interested in science-related careers, pre-college teachers, and undergraduates enrolled in the standard introductory physics courses. Working with the Physics Education Group has provided varied experiences to Dr. McDermott, some of which have become the subject of investigations funded by the Research in Science Education (RISE) Program, as well as the Development in Science Education (DISE) Program. Dr. McDermott has published widely on the teaching of physics to students and currently to pre-college teachers, and her findings have had an important impact on physics curriculum writing.

I. Introduction

The Physics Education Group in the Physics Department at the University of Washington is conducting a comprehensive program that integrates research in physics education, curriculum development based on this research, and physics instruction. The Physics Education Group includes physics faculty, visiting faculty, research and academic associates, and doctoral students doing their research in physics education. This paper describes the instructional, research, and curriculum development components of the program and gives examples of their interaction.

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RISE SED78-17261 - Investigation of Conceptual Development in the Study of Motion
DISE SED79-18997 - Preparing Academically Disadvantaged Students in Science Through Concept-Based Modules
PCTD SPI79-02301 - Production of Increased Science Competence in Elementary and Secondary Schools

II. Comprehensive Program

A. Instructional Component

All members of the Physics Education Group are actively engaged in instruction. We have experience teaching physics to students with a wide variety of ability and preparation. Our students include minority students interested in science-related careers, pre-college teachers, and undergraduates enrolled in the standard introductory physics courses.

1. Minority Undergraduates Interested in Science-Related Careers
For the past five years, the Physics Education Group has been conducting a special sequence of physics courses[1] designed to prepare minority students for mainstream science courses. Each year about 50 students in the University of Washington's Educational Opportunity Program (EOP) enroll in this special program. The courses are laboratory-centered, with a great deal of interaction between the instructors and students. We have assembled support for the instructional costs from the Physics Department, Graduate School, and a Health Sciences program. The development of curriculum based on our experience in this course is described in Section II.C.1.

2. Pre-College Teachers
For the past 10 years, our group has offered courses for pre-service and in-service teachers. The pre-service course for prospective elementary school teachers was originally developed by Arnold Arons with UPSTEP support. We have also developed a special year-long course in physics which is required for certification to teach high school physics. In addition to these two regular course offerings in the Department, there is an extensive in-service teacher education program supported in part by a Pre-College Teacher Development in Science grant. In-service courses are offered twice a week.

3. Undergraduates in Standard Introductory Physics Courses
Members of the group also participate in the regular instructional program of the Physics Department. Thus, the group has direct access to the traditional physics student enrolled in pre-professional general introductory physics and in calculus-level introductory physics courses.

B. Research Component

Our research focuses on systematic investigations of student difficulties in various domains. Currently, our major research effort is the Research in Science Education (RISE) project in which we are investigating student understanding of the concepts of motion among the student populations mentioned above. A second area of research is the identification of specific difficulties in learning science that hinder the progress of academically disadvantaged students in mainstream science courses. This investigation is part of our Development in Science Education (DISE) project in which we are developing curricula to address student difficulties common to the study of science in general, rather than specific to physics.

1. Research in Science Education (RISE) Project

In our RISE project, we are conducting an empirical study of student understanding of concepts of motion. Initially, the research focused on kinematics. Research currently under way centers on an investigation of student understanding of the concepts of dynamics.

In this study, the criterion selected to assess understanding of a concept is the ability to apply the concept correctly to simple motions of real objects. The primary data source has been the individual demonstration interview in which students are asked specific questions about simple motions they observe. Data are also obtained from student responses on homework assignments, examinations, instructor-student dialogues, and group and class discussions. As the research progresses, results are incorporated into our instructional program and into new curricula. These, in turn, suggest further questions for research.

The results of our study on student understanding of kinematical concepts, with emphasis on instantaneous velocity and acceleration, have been reported.[7,8] In conjunction with this research, we have developed a curriculum in the form of a module on kinematics which addresses specific difficulties that have been identified in the course of our investigation. A description of a portion of this research in kinematics can serve to illustrate the interaction among the research, curriculum development, and instructional components of our program.

In our empirical study of student understanding of the concept of acceleration, we have focused on the qualitative understanding of acceleration as the ratio of change in velocity to the corresponding change in time ($\Delta v/\Delta t$). Acceleration Comparison Task 1 was designed to probe various aspects of student understanding of acceleration. This task was administered as an individual demonstration interview to about 200 students representing all populations included in our study.

In Acceleration Comparison Task 1, students observe the motions of two identical steel balls that roll down straight aluminum U-channels set side by side. Although both tracks are inclined identically, the channels are of different widths as shown in Figure 1. Thus, one of the balls, ball A, has a smaller acceleration than the other, ball B.

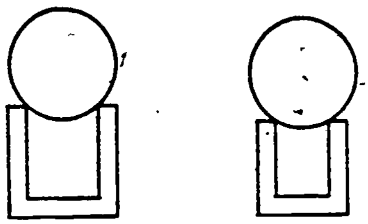


Fig. 1. Cross-sectional view of U-channels used in Acceleration Comparison Task 1.

The apparatus for Acceleration Comparison Task 1 is illustrated in Figure 2. Both balls are released from rest. Ball A, initially behind ball B, is released first. The apparatus was carefully designed so that both balls reach a tunnel at the end of the inclined tracks at the same instant and with the same velocity. The two motions are illustrated in the graphs in Figures 3 and 4, neither of which is used in the interviews. Acceleration Comparison Task 1 is described in more detail in a paper reporting on this research in the American Journal of Physics in March 1981.

The interviewer begins by showing the student the motion of each ball separately. It is clear that both balls accelerate. The motions are then run together and the student is asked: "Do these balls have the same or different accelerations?" The two most common correct lines of reasoning are the following: (1) Balls A and B have the same final velocity. Since ball A is already moving when ball B is released, ball B's velocity changes more in the same time. Thus ball B's acceleration is greater than ball A's. (2) Both balls have the same change in velocity from zero to the same final speed, but ball B is released later and undergoes this velocity change in less time. Thus ball B's acceleration is greater than ball A's.

The interviewer assists the students in making the observations necessary for comparing the accelerations by directing attention to the motion of the balls at the times when each ball begins to move and when they both enter the tunnel. In order to complete the task,

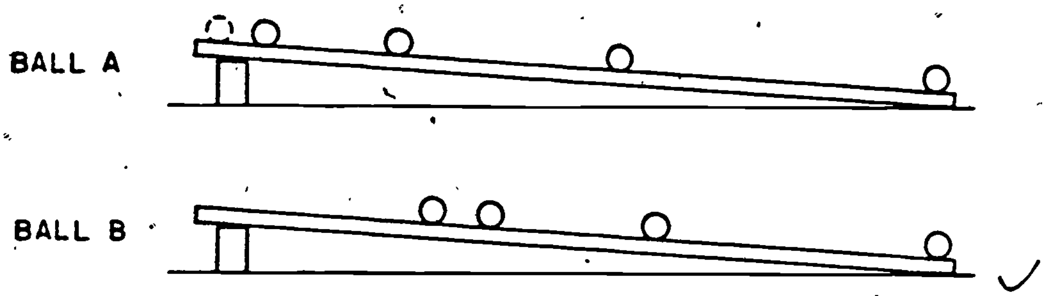


Fig. 2. Acceleration Comparison Task 1. Motion is from left to right. Successive positions are shown as they would appear in a strobe light photograph. Dashed circle indicates initial position of ball A. Solid circles indicate corresponding positions of balls at equal time intervals.

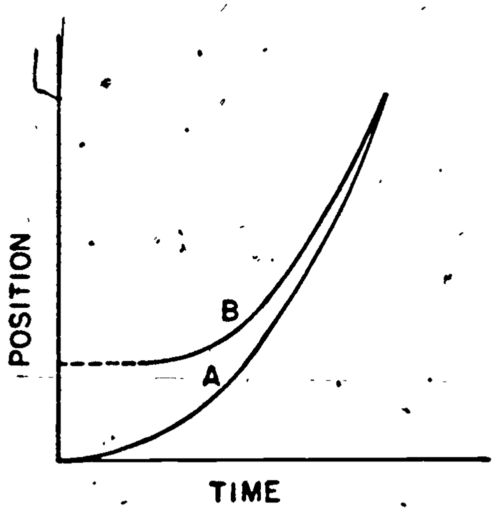


Fig. 3. Position-time graph of motion demonstrated in Acceleration Comparison Task 1. Dashed line indicates position of ball B from instant ball A is released until ball B is released.

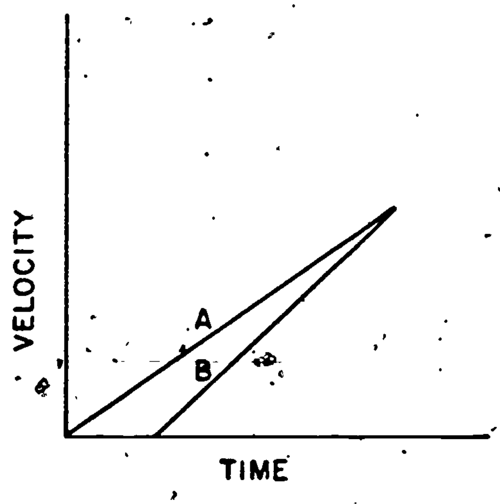


Fig. 4. Velocity-time graph of motion demonstrated in Acceleration Comparison Task 1. Balls reach the same velocity just as they enter a tunnel at the bottom of the incline.

the student must recognize these observations as necessary and be able to combine them appropriately. Success in this task was taken as an indication that the student understood the concept of acceleration as the ratio $\Delta v/\Delta t$.

The failure rate on this task was very high. Even among students in the calculus physics course, only 40 percent of the students in our study were successful after they had studied acceleration in the course. Traditional instruction of this concept does not seem to be adequate for most students to apply it correctly to a real motion. A careful analysis of the reasons for failure on the acceleration comparison task pinpointed a number of conceptual difficulties. Some of these indicated a confusion between the concepts of velocity and acceleration, an inability to deal with the concept of change of velocity quantitatively, and a lack of understanding of acceleration as a ratio.

As described in Section II.C.2, the research on student understanding of concepts of motion has guided the development of curricula in the form of a module on kinematics. The use of these curricular materials in our courses not only provides a means for evaluating and improving the curriculum as it is being designed, but also provides the opportunity for continuing the study of student difficulties. As students use the materials, we gain new insights into their problems and this suggests new questions to be systematically studied.

2. <u>Development in Science Education (DISE) Project</u>

In the course of the research associated with our curriculum development project, we have identified a number of specific difficulties encountered by our EOP students in learning science. We have grouped these difficulties into four somewhat overlapping categories. Although other schemes might work equally well, we feel this organization constitutes a useful system that can readily be translated into implications for instruction. The four categories are listed and briefly illustrated below.

a. <u>Confusion between two concepts that apply to the same situation</u>

A major problem for our students has been the lack of an adequate understanding of basic concepts. It is easy for students to learn to repeat definitions of such concepts, but this is not sufficient. For a concept to be of value to a student, the student must be able to distinguish it from related concepts and to select the one appropriate to the task at hand. Over 50 percent of our students initially confuse the concepts of mass and volume, density and concentration, heat and temperature, speed and position, and velocity and acceleration. Our curriculum is designed to help students confront and resolve these confusions.

b. Problems with scientific reasoning

We have found that the reasoning difficulties faced by our academically disadvantaged students are substantially the same as those found in the general student population, but more frequent and severe. Recently, many authors have called attention to a widespread need among college students to develop reasoning skills such as proportional reasoning, logical implication, combinatorial reasoning, control of variables, and hypothetico-deductive reasoning. We believe that student performance on these reasoning skills should be examined in the light of coherent subject matter such as physics, rather than through exercises and tasks that attempt to separate scientific reasoning from scientific content. It has been our experience that the ability to use these reasoning processes is heavily dependent on the context.

c. Inability to reason by analogy and to transfer reasoning to new contexts

One of the instructional devices widely used in the sciences is the analogy. We have found that our students are severely limited in their ability to follow instruction by analogy. For example, we introduce proportional reasoning in the context of mass, volume, and density. Even when the students become fairly competent at executing and explaining the reasoning in these problems, we find that few are able to solve exactly analogous problems involving circumference and diameters of circles.

d. Lack of connection between reality and representations

Students must be able to use representations of reality such as verbal statements, diagrams, models, graphs, and formulas to benefit fully from instruction and to communicate with others. In addition to having the skills needed to work with representations, e.g., memorizing laws, plotting graphs, solving equations, etc., students must also acquire the ability to connect these representations with one another and with real situations. An inability to make these connections is characteristic of most of our students as they enter the EOP physics class.

As specific difficulties in the above four categories have been identified and explored in detail, we have designed instructional materials to help students overcome them and have used these curricular materials in our courses. This interaction among the research, curriculum development, and instructional components of our program is illustrated in the next section.

C. Curriculum Development Component

The third major component of our program is curriculum development. Currently the primary development effort is the DISE project which focuses on curricula to prepare academically disadvantaged students for mainstream college science courses. We are also developing curricula based on our motion research under our RISE grant. These materials are intended for use by students with a wide variety of preparation in physics.

The development of curricula is firmly rooted in our classroom experience. After 5 years of working with academically disadvantaged students; two features of our approach to instruction have emerged as guiding principles for the design of curricula: (1) concepts and reasoning should be addressed together, and (2) abstraction and generalization should be preceded by direct experience.

It is our belief that concept formation and reasoning development are mutually dependent and must be addressed together. If the reasoning skills of students are not sufficiently developed, it is often fruitless to attempt to teach them formal scientific concepts because many concepts are inseparably linked with particular lines of reasoning. Conversely, we believe that development of reasoning skills cannot be fully realized unless these skills are applied to significant subject matter which is part of a cohesive body of knowledge. Courses that focus only on reasoning and ignore formation of scientific concepts or that introduce subject matter only incidentally are likely to be of limited usefulness in preparing students for mainstream science courses. This assertion is based on our experience that the transfer of reasoning skills by the students from one context to another is quite limited.

Our experience in the classroom has strengthened the conviction that for students whose reasoning skills are not yet fully developed, scientific concepts should be introduced in the laboratory. Many of our students initially do not distinguish between naming and understanding a concept. To them, a repetition of words in correct juxtaposition represents understanding. To forestall this fixation on words, we introduce technical terms only after the ideas behind them have been explored in the laboratory.

1. DISE Project

In our DISE project, a curriculum in physics and physical science is being developed to help prepare academically disadvantaged students for success in mainstream science courses. The setting for this project is the special program in the Physics Department for students (mostly minority) in the University of Washington's Educational Opportunity Program (EOP). The close relationship between instruction in the EOP physics course and the development of curriculum for these students is illustrated in a series of three articles which were published in the *Journal of College Science Teaching* in January, March, and May 1980.[1]

We plan to produce six modules which together comprise about 2 years of academic work. The topics have been chosen to form a conceptual basis for later work in the physical sciences. The titles include *Properties of Matter*, *Kinematics*, *Astronomy*, *Heat and Temperature*, *Electricity and Magnetism*, and *The Atomic-Molecular Model of Matter*. The first module, *Properties of Matter*, lays the foundation for the others which may be selected in any order according to the instructor's preference and students' needs.

The first two modules have been printed in trial editions and are being pilot-tested at the University of Washington and other institutions. Although the curriculum is being developed to help prepare minority students for mainstream science courses, we have found that the materials are effective with pre-college teachers and with students who have already had some preparation in physics.

These curricular materials embody the design principles mentioned earlier. For example, in accordance with the procedure described by Arons, practice with proportional reasoning is embedded in study of subject matter. Over a period of a year, the students work with proportions in the contexts of density, pi, concentration, chemical proportions, and uniform velocity. For each proportion, the result of carrying out the division is interpreted as the number of units in the numerator for every one unit of the quantity in the denominator.

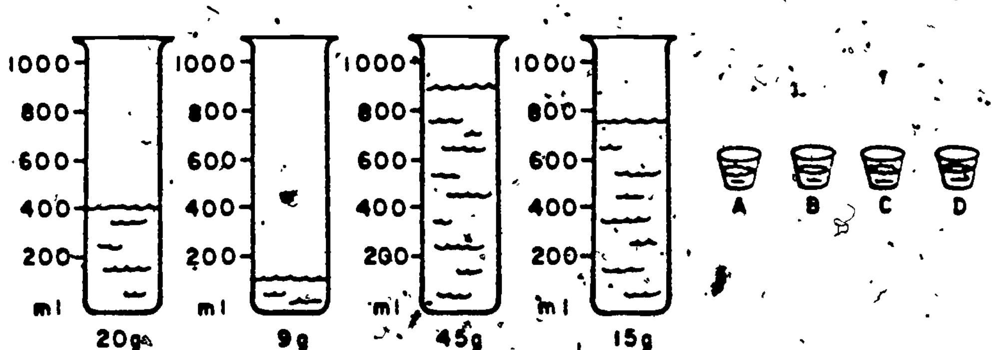
The chart in Figure 5 summarizes the treatment of proportional reasoning in our curriculum. We have found that extensive exposure to proportional reasoning in different contexts is necessary before significant transfer to new topics is achieved. This illustrates two of the difficulties identified by our research: the persistence of trouble with scientific reasoning and the limited ability of the students to reason by analogy and to transfer reasoning to new contexts.

Density	(number of grams for each cm^3)	
	⇩	no transfer
π	(number of units of circumference for each unit of diameter)	
	⇩	very little transfer
Concentration	(number of grams of solute for each 100 cm^3 of solvent)	
	⇩	50% transfer
Chemical Proportions	(number of grams of one element for each gram of another element)	
	⇩	almost 100% transfer
Uniform Velocity	(number of cm for each second)	

Fig. 5. Cycles for Proportional Reasoning.

The failure to connect reality with its representations is taken into account in a second example of our approach to curriculum development. This excerpt, which is taken from the study of solutions, illustrates the way in which the laboratory is used to help form the quantitative concept of concentration and connect this number with observable properties of solutions. The experiment described is the first of many that involve solutions and serves as the students' first exposure to this topic. Each student works individually with a staff member on the following task: the student is shown four beakers containing salt water solutions as in Figure 6. The beakers contain very different volumes of water that can be determined by reading the calibrated scales. In front of each beaker is written the mass of salt that it contains.

The student is given a sample of solution from each beaker and is asked to match each sample to the beaker from which it came by tasting the samples. The student is not allowed, however, to taste the solutions in the containers. To match correctly, it is necessary to perform calculations that take into account both the mass of salt and the volume of water.



[illegible] 6. Introduction to Concentration. The student is [illegible]d to taste each salt water sample and then match it t[illegible]e of the beaker solutions.

Most students (about 60 percent) initially match the salt water samples and beaker solutions incorrectly, usually because they focus only on the total mass of salt in the beakers and ignore the volume of water in which the salt was dissolved. For the students who consider only the salt, the staff directs attention to the role of the water in the beakers through such questions as "Does the amount of water affect the saltiness?" and "How could you take the water into account?" Although some of the students need further guidance, at this point most realize that the saltiness of the solutions is related to "the amount of salt compared to the amount of water." While some cannot see how to make this comparison, most divide the mass of salt by the volume of water (or vice versa), interpret the resulting number correctly, and make the proper match between the beaker solutions and the samples tasted. At the end of the exercise, the instructor states that the number obtained by dividing the mass of salt by the volume of water is called the <u>concentration</u> of the solution.

In this example, the laboratory setting has allowed the staff to introduce the concept of solution concentration by providing a situation in which the concept is created out of necessity. Only after this experience is the concept named. This procedure is typical of the way new concepts are introduced in our curriculum.

2. <u>RISE Project</u>
We have used the results of the research from our RISE project to guide development of an instructional module on kinematics. On the basis of the research described earlier in Section II.B.2, for example, we designed an instructional demonstration to confront the confusion of velocity and acceleration and to help the student connect these concepts to actual motions.

In the demonstration illustrated in Figure 7, the students are shown two identical steel balls rolling on tracks placed side by side. Each track consists of a level section followed by a downward sloping section. The sloping sections start at the same place and are identically inclined. Ball A rolls on a wider track and thus has a smaller acceleration on the incline. The two balls begin to move at the same time, but ball A starts out behind ball B with a greater initial velocity. The two balls reach the ends of the level sections at the same moment. Ball A will, of course, move out ahead of ball B as it begins to roll down the incline. Although both balls accelerate on the incline, ball B has the larger acceleration. When ball B attains the same velocity as ball A, it is still behind ball A. For a short time, the separation between the balls remains almost constant, indicating that the balls have the same velocity. Thereafter, ball B begins to close the gap, but the track ends before ball B overtakes ball A. The two motions are illustrated in the graphs in Figures 8 and 9, neither of which is used in the interviews.

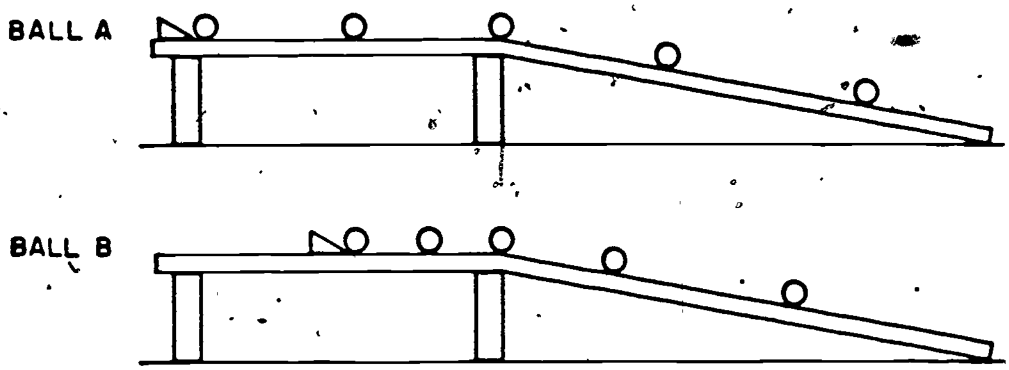


Fig. 7. Instructional Demonstration. Motion is from left to right. Successive positions are shown as they would appear in a strobe light photograph. Solid circles indicate corresponding positions of balls at equal time intervals. Balls have the same velocity at the last positions shown on the inclines.

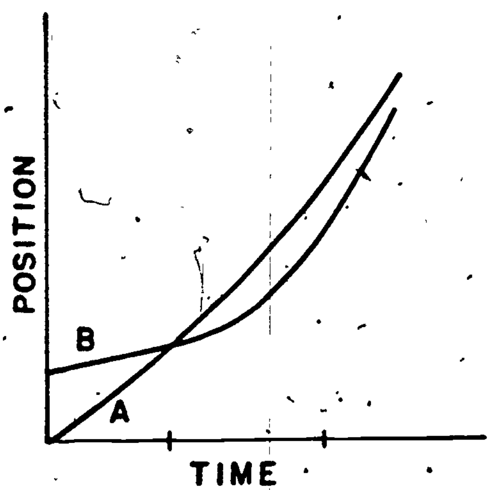


Fig. 8. Position-time graph of motion in Instructional Demonstration. Both balls begin to accelerate at the same time when they are side by side at the top of the incline.

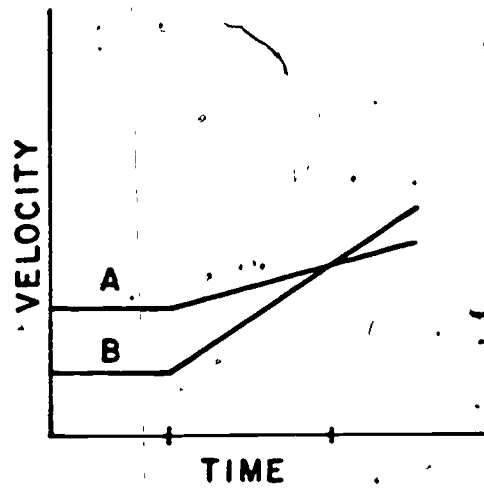


Fig. 9. Velocity-time graph of motion in Instructional Demonstration. Ball A has a larger initial velocity but a smaller acceleration than ball B.

The motions are run together and the students asked: "How do the accelerations compare?" A correct comparison can be made by reasoning as follows: At the instant both balls are at the beginning of the inclined track, ball A's velocity is larger than ball B's, but later they have the same velocity. Thus, ball B changes velocity more in the same time and has a larger acceleration.

Many students, however, respond that the two balls have the same acceleration. In the ensuing discussion, they usually make reference to the short time when there is a constant separation between the balls as they move down the tracks. These students use an observation that indicates the balls have the same velocity to justify their claim that the balls have the same acceleration. The demonstration thus provides a situation in which a confusion between the concepts of velocity and acceleration becomes evident and can be directly addressed.

The dialogue between instructor and students initially focuses on the concept of instantaneous velocity and then continues with a discussion of the definition of acceleration. The instructor directs the students' attention to the need to consider the instantaneous velocities of the balls at two different instants in order to compare their accelerations. The students examine the changes in velocities for each ball and the time intervals required for these changes. They then compare the ratios of ($\Delta v/\Delta t$) for the balls and determine which has the larger acceleration. The discussion provoked by this demonstration provides the instructor with the opportunity to confront the confusion between velocity and acceleration directly and to help the students separate these concepts.

As a result of the type of instruction illustrated by this demonstration, the students in the EOP physics course achieved a qualitative understanding of acceleration as a ratio that matched the understanding acquired by students taking calculus-based physics. About 20 percent of the calculus physics class could perform satisfactorily on Acceleration Comparison Task 1 before instruction, while 40 percent succeeded on a post-test. From none being successful on a pre-test, the EOP students also progressed to 40 percent post-test success. Such an improvement did not occur among students enrolled in any of the standard lecture courses included in our study.

3. <u>Pre-College Teacher Development in Science Project</u>

With assistance from the National Science Foundation, inservice teacher education has been a continuing activity in the Physics Department for many years. Currently through a Pre-College Teacher Development in Science grant, the Physics Education Group offers workshops to teachers twice a week after school. There has been a mutually enriching interaction between our teacher education activities and research and curriculum development under our RISE and DISE grants. By including teachers in our studies of conceptual understanding, we have increased our data base and made possible greater generalization of our findings. We have found that curriculum developed for the EOP students has been very effective with teachers. In turn, materials originally designed for use in the in-service workshops have worked well with the EOP students and have been incorporated in the modules being produced under our DISE grant.

III. Conclusion

It has been our experience that the research, curriculum development, and instructional components of our program continually reinforce one another. Figure 10 shows the interaction of these components. The continuous involvement with students in the classroom has proved fruitful in suggesting further questions to be investigated systematically through our research. We feel that the process of immediately using and revising curriculum as it is developed increases the likelihood of producing materials responsive to student needs. The instructional program thus provides a setting that allows for the constant re-examination of the results of research and curriculum development. It is our belief that a comprehensive program involving research, curriculum development, and instructional components is an effective approach to improving science instruction.

Acknowledgments

The work reported here is the result of the combined efforts of all members of the Physics Education Group. Mark Rosenquist and David Trowbridge, however, deserve special recognition for their substantive contributions. In addition, the assistance of Emily H. van Zee and Herbert Lin in the preparation of this paper is gratefully acknowledged.

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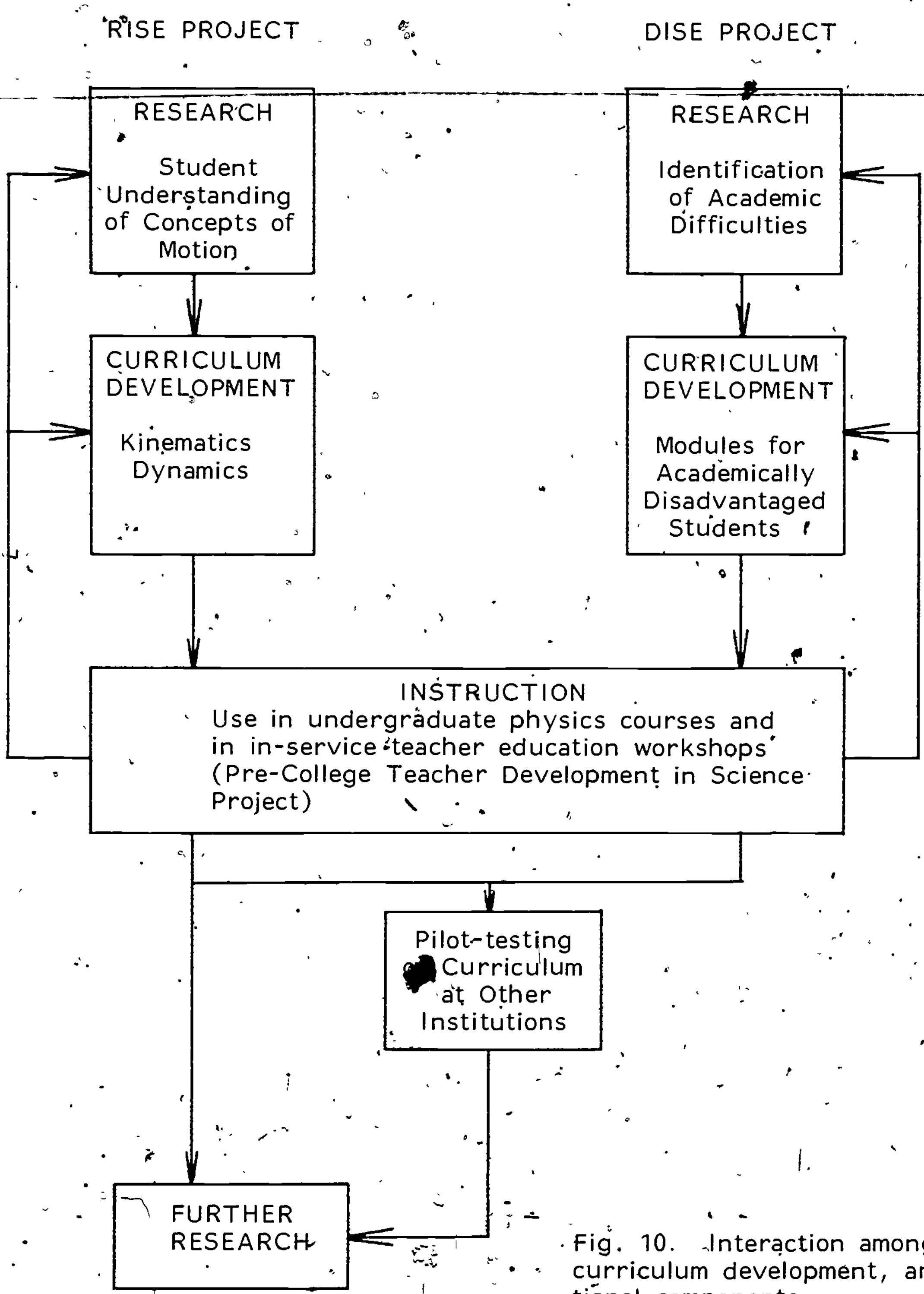

Fig. 10. Interaction among research, curriculum development, and instructional components.

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THE LOGICAL COMPETENCIES PROJECT: THE INTERACTION OF CURRICULUM DEVELOPMENT AND RESEARCH*

James T. Robinson
Center for Educational Research and Evaluation
Louisville, Colorado 80027

Dr. James T. Robinson has been associated with the Biological Sciences Curriculum Study as Staff Associate, Project Coordinator in the Human Sciences Program and as Director of the Center for Educational Research and Evaluation. He is at present Educational Programs Specialist in the Boulder Valley Public School System in Boulder, Colorado. Before Dr. Robinson became connected with BSCS he taught at Teachers College, Columbia University, after several years of varying experience in the California secondary school system as both teacher and administrator. His doctoral degree is in science education from Stanford University. Dr. Robinson has written widely on education, on science and on science education. He has been principal investigator of two NSF projects and one from the then Office of Education. With Dr. John W. Hole, Jr., he has produced over 15 filmstrips in biology.

When the opportunity to develop an entirely new science curriculum for early adolescents became a reality to some of us at the Biological Sciences Curriculum Study Company (BSCS) in 1971, we immediately thought of all of the research opportunities that such a project could provide. The climate of that day, however, did not enable us to do anything about research. By 1973, as we began field testing the first year of a 3-year interdisciplinary science program, the prospect of gathering data for longitudinal studies became compelling.

This program, named the Human Sciences Program in 1972, was funded by a grant from the National Science Foundation (NSF). We planned a formative evaluation design for the program. But, from the start, the project staff was confronted with the usual tug-of-war for allocation of resources between producing curriculum materials and providing the appropriate means for evaluating the materials.

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Then President Nixon came to our rescue and solved our problem. He cut all NSF projects by 50 percent as we began field testing in the fall of 1973. We allocated most of our resources to the development task for the second-year materials.

We implemented parts of our evaluation plan by organizing our data management system so that data already being collected could be saved and utilized for analysis in the future.

In the spring of 1974 our group of scientists and teachers/writers presented strong arguments to us to capitalize on the 3-year field test opportunity and to gather additional data, if we could, before the end of the first year of field testing.

I am presenting this background of the current project to convey to you the strong feelings of scientists, science educators, and teachers of the value--indeed, the obligation--of people working in the schools and gathering data from teachers and students to make optimal use of that opportunity.

A second set of events in the mid-1970s convinced us of the need to couple research with development and also to incorporate summative evaluation with formative evaluation when a curriculum is innovative. The Man: A Course of Study (MACOS) controversy showed the inadequacy of formative evaluation. Critics of anything new immediately find the old materials suddenly blessed with new virtues. The old materials that were the source of the criticism that led to support for new curriculum development evolve into materials that are the "disciplines" that teach the "basics." The innovative materials must suddenly have new virtues; they must teach everything the in-place materials do--at a higher level, of course--and then prove that they do their own thing effectively. This demand cannot be resolved with data from formative evaluation. It requires careful formative and summative evaluation, and it usually requires coupled research studies.

This three-pronged approach is essential for any innovative materials development project, but it is even more critical for materials that contain drastically different approaches to disciplines, the laboratory, the way students work with the materials, and to teaching strategies. It is especially critical if you want the materials to be published. To make certain we all understand what I mean, I'll share with you a definition of "innovative" that a science editor of a major publishing company gave at a conference several years ago. He said an innovative curriculum is one that, when picked up and scanned rapidly by a prospective user, could not be immediately used.

The formative evaluation of Human Sciences provided unique opportunities for data gathering that could be used in one framework for evaluation and in another for research. For example, data gathered over a 3-year period were coded by the individual student, teacher, and school, but the students being taught by one teacher were the unit of study. In this way we minimized cost by cleaning up the teacher and school codes, and made our computer runs and other data analyses without the data cleanup required when the student is the unit of analysis. The long-range potential to use the student as the unit of analysis in future research was delayed, but not lost, and resources needed for formative evaluation were used for that purpose.

My current project, "Logical Competencies and Activity Selection Patterns in Early Adolescents: A Longitudinal Study" (SED 79-19312), was designed to prepare Human Sciences evaluation data gathered between September 1973 and June 1977 as a data base for research and to conduct two small studies to show the potential of the data base for further research. The major part of the project is the preparation of a codebook and a machine-readable user's guide, and the completion and verification of the SPSS archive file of the data. To understand the data base you need to know a bit more about the Human Sciences Program as a unique science curriculum resource for future research studies in science. My argument has support from studies of class size such as those done by Glass and Smith (1979). They found that many studies attempting to find effects of class size on achievement found no differences. These studies on class size generally dichotomized the variable as greater than, versus less than, 30, but mean "large" classes were in the low 30s and mean "small" classes were in the high 20s. It is not surprising that class size on this basis makes no difference in achievement. When they compared class sizes of less than 15 with classes over 30, they found increased achievement with "small" class size. I think we have similar problems with curriculum comparisons. Uniquely innovative curricula like Human Sciences may be of critical value in studies of science teaching and learning because they present large differences from extant curricula. There are many innovative curricula in mathematics and science produced in the 1960s and 1970s that might be reexamined for their research potential.

The Human Sciences Program was designed to meet the needs, underlying concerns, and developmental tasks of early adolescents. In developing the curriculum framework, we had the opportunity to develop an entirely new approach to science instruction, not merely to revise existing curricula. We did this by asking the question, "How can the science disciplines contribute to personal, social, and cognitive development of early adolescents?" not the usual curriculum design question, "How can we simplify the sciences for this student group?"

Seven field test sites in seven states were selected for field testing. Five of the sites were middle schools (grades 6-8), and two were elementary schools (grades K-6). Students from the elementary schools transferred to junior high schools for grades 7 and 8 and continued in Human Sciences test classes at these sites. Twenty-one

6th-grade classes, three at each site, were included in the initial testing. It was anticipated that at least one test class would be included at each site during the 8th-grade test. Students were allowed to transfer from test classes to regular science classes at any time during the test period. Schools agreed to provide as many test classes in the second and third year of testing as were needed to accommodate students wishing to continue in Human Sciences.

The Human Sciences Program divided each school year into sections of from 6 to 9 weeks, during which a particular material (module) was provided. The term module was selected to differentiate these materials from resource units and text units. Each module contained everything needed for two class groups of 30 students each day. When I say "everything needed," I include all unique materials, but leave out ordinary laboratory equipment. Experimental modules did include library resources where appropriate.

A key characteristic of the program was the provision for a bounded free-choice environment for students. By "bounded" I mean that students were asked to stay within the boundaries of the module and activity design of the program and to remain essentially within the activities or activity extensions provided in each module. Each module contained from 30 to over 50 individual activities. Each activity consisted of several pages of printed material plus all of the equipment, supplies, and other materials needed to conduct the activity successfully. There were more activities in each module than any single student could complete within the allotted time period. No activities were prescribed.

Students had choices of the activities they would do. In some instances the opportunity was provided for students to devise their own activities. The choice of activities made it possible to include many that would not be considered feasible in classes where every student is required to do every laboratory or other kind of activity. Not only could students choose their activities but they could also choose whether they wished to work alone, with a partner, or with several students. This, then, is what is meant by a "bounded, free-choice environment." Every activity in every module was designed to have educational value for some students. Choice was not from the whole world but from the activities in a particular module and usually only from a segment of a module at any one time. Each module was designed around a particular theme. Subdivisions within modules (problem areas or clusters) provided internal organization for closely related activities.

Part of our formative evaluation was concerned with student choice of activities. The activity choices of each student in test classes were gathered, as were achievement data and other data specific to each module. At the end of the first year of testing, an attitude scale and a test of logical thinking were given to students in test classes. An attitude measure and a revision of the logic test were administered to test class students at the end of the third year of testing. Data for all students (about 800) who were in test classes at any time during the 3-year field test were built into an SPSS system file as they were gathered. Some 240 students were in field test classes for the full 3 years.

Field testing of the first year, designated Level I, was conducted in seven schools geographically distributed in different parts of the United States. Schools were selected for geographic location, school organization, distribution of student characteristics, and willingness of the school district administrators and parents to make a commitment to participate in the 3-year field test program.

When the data base is complete, it will contain some 800 cases with about 2,000 variables. New data are being added to the data base by the complete recoding of some critical variables such as scores of the first logic test. This will make it possible to ask research questions about changes in logical competencies of students over a 2-year period.

A coding system for the activities students chose is being developed to code each of the approximately 550 activities tested during the 3-year evaluation period. Activities are being coded on four characteristics or descripta: activity approach, type of knowledge, discipline, source of the knowledge, and what students do when they study the activity. An activity file is being prepared as a separate SPSS system file.

The user's guide is being prepared to be transferable from one computer system to another. It is being prepared using guidelines and suggestions of Robbin (1974-75) and Roistacher (1979). The user's guide will document the selection of test sites and other information about the source and conditions under which the data were gathered. The codebook will provide SPSS variable names, variable labels, value names, value labels, and frequency distributions of all variables. The SPSS data file will be available on tape. The user's guide and codebook will be available on tape, as hard copy, or may be transferred to word processors with communications capabilities.

Most research in science education is conducted by investigators gathering their own data, albeit with a small group of subjects. More recently, Glass (1978) has advocated the use of meta-analysis to combine data from many published studies as a useful research tool. He domonstrated the usefulness of meta-analysis in research on psychotherapy (Glass and Smith, 1976) and the relationship of class size to achievement. Other researchers have utilized meta-analysis procedures advantageously since Glass's procedures were published.

Published summary statistics have limitations that also become limitations in meta-analysis procedures. Natural and social sciences researchers have long accumulated data, stored these on computer tapes, and made them available to the research community. Data tapes made available by government agencies such as the Census Bureau have been used extensively as data sources for research. The costs of securing valid data are increasing and more attention needs to be given to data documentation, data sharing, and the multiple use of such a resource. Yet, this kind of resource is not readily available for science education research.

Data files must be transferable to a variety of computer systems. Transferability can be ensured if the preparation of the data systems is planned and executed with transfer as a goal. Without such care in preparation, data systems will not be usable if prepared on one hardware system, for example, an IBM system, for use on another system such as Univac or CDC.

Documentation is a major consideration for the preparation of data files, codebooks, and user's guides. Currently, there are few resources to guide those desiring to prepare such materials. The existing resources and others are being adapted in the current project to prepare the data tape, codebook, and user's guide as a model for the generation of similar data bases by other researchers in science education. This example and a description of the technical problems that need to be solved in the preparation of transferable data systems are now being completed. Finally, requirements for effective dissemination and aids for potential users of data systems will be prepared.

What are potential payoffs from attending more carefully to interactions among development, evaluation, and research? In the formative evaluation of Human Sciences we found an interesting outcome. At the completion of the testing of one module with a group of 8th graders, we administered a science questionnaire that included a semantic differential with 18 bipolar adjectives. Conceptually, we postulated that there would be four dimensions or subscales within the instrument. Since we had tested this instrument with students in previous situations, both in Human Sciences and regular science classes, we had a good idea that the conceptual structure would hold, which it did. Students were asked to mark two semantic differentials, one to represent their feelings about each of two courses: first, the Human Sciences module which they were just completing; and second, their science course prior to studying the module. That was the course they had studied from September until the first week in April of the same school year, 1976-77. The bipolar adjectives were scored on a scale from 1 to 7 with 1 for the value nearest the negative adjective and 7 for the value nearest the positive adjective.

Table 1 shows a comparison of the mean scores of the students' attitudes toward Human Sciences, in this case an 8th-grade module, and toward previous 8th-grade science, on the four subscales. T-tests show significant differences between student responses to Human Sciences and to 8th-grade science on each of the four subscales.

The magnitude of the differences between student attitudes toward the two courses is apparent in both the p values and in calculations of "effect size." "Activity" shows a large effect size of .80; "Evaluation" and "Interest" show effect sizes of .72; and "Value," an effect size of .36.

Table 1.

Comparison of mean scores of student attitudes toward Human Sciences and 8th-grade science on four subscales of the Science Questionnaire

	Human Sciences		8th-grade Science		One-tailed T-test		
Subscale	Mean	SD	Mean	SD	df	t	p
Evaluation	27.88	5.50	22.10	7.93	267	5.54	.001
Value	27.21	5.47	24.52	7.39	267	2.72	.005
Activity	26.56	5.47	20.36	7.75	267	5.66	.001
Interest	16.25	4.16	12.33	5.41	267	5.12	.001

Further examination of student responses to the semantic differential attitude scale shows significant differences between the way boys and girls responded to the instrument. In Figure 1 you will notice that on each of the four subscales girls and boys differ. On the "Evaluation" scale, we see that girls were significantly more positive toward Human Sciences than were boys, though both were highly positive. Conversely, girls were less positive about their regular science course than the boys were. This same pattern repeats itself across the four subscales. But on the "Interest" subscale (see Figure 2) we have significant differences for both courses. You will also note that on the "Activity" and "Interest" subscales, the attitudes of students were essentially neutral toward the regular science course. These findings replicate attitude findings reported previously (Robinson, 1980) on a different 8th-grade population that had completed three years of testing the experimental Human Sciences Program, exclusive of this particular module.

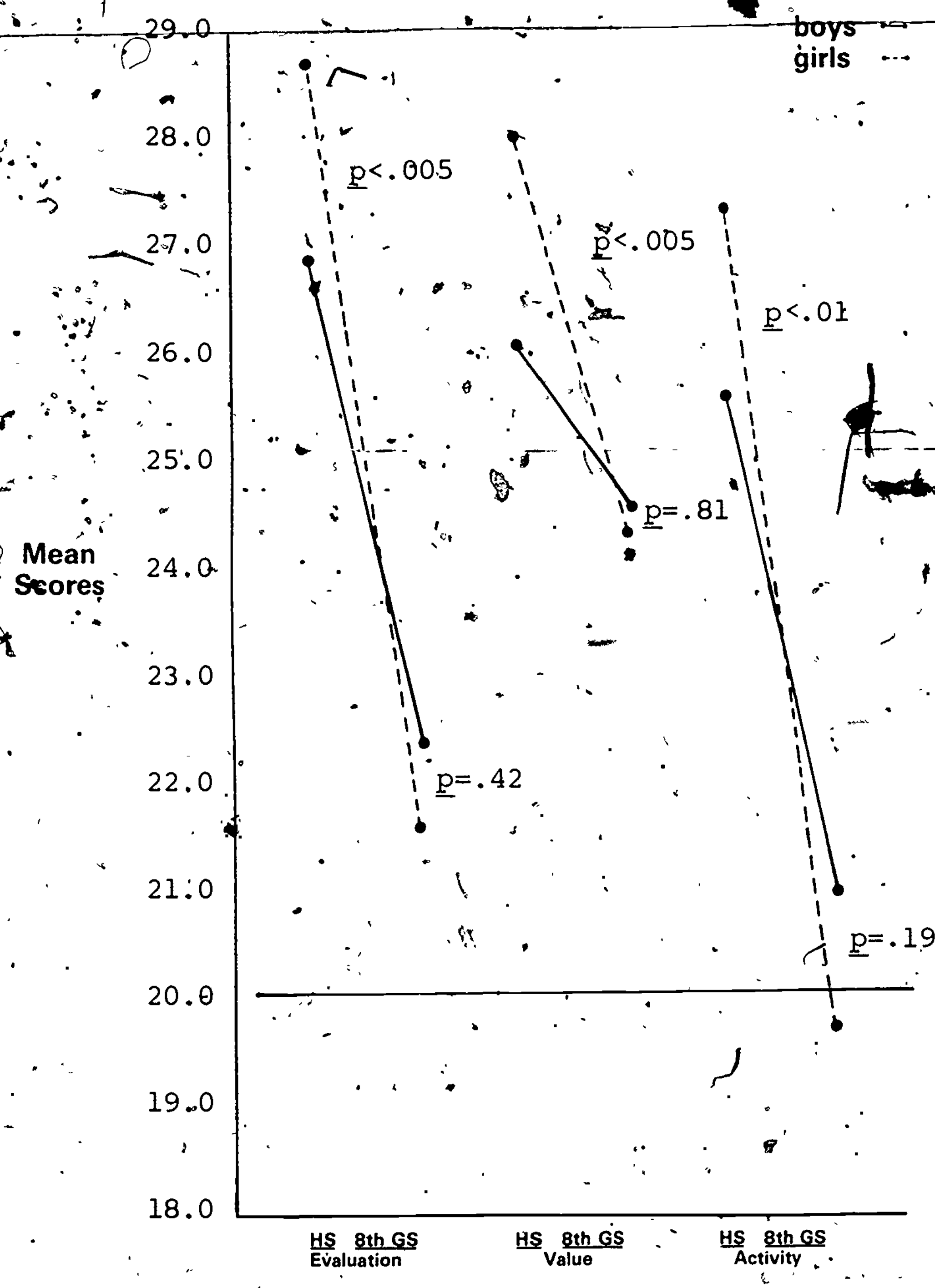

Figure 1. A comparison of mean scores of boys and girls on three attitude subscales. (N=268)

Note. The horizontal line is the neutral mean score on the subscales.

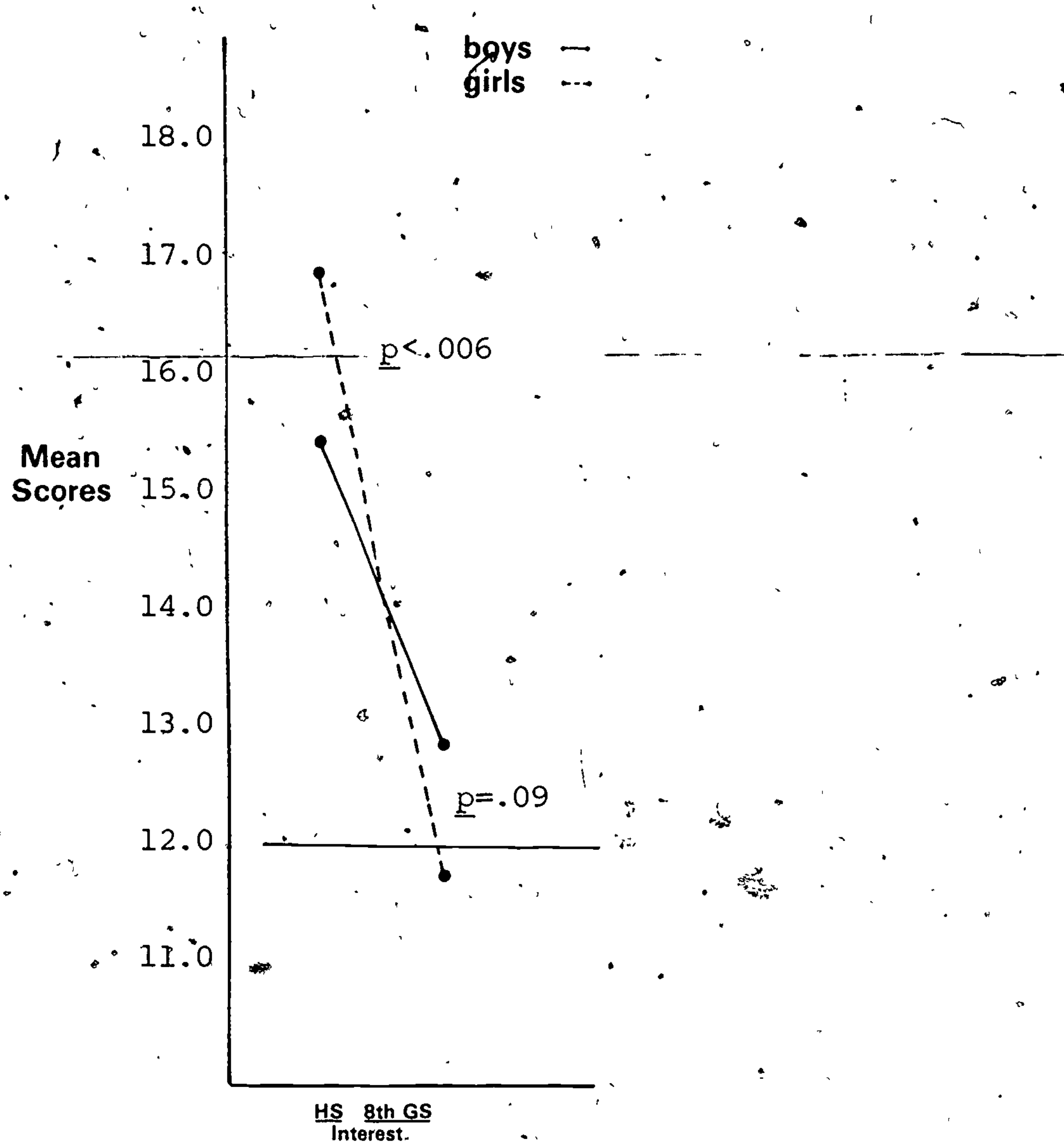

Figure 2. A comparison of mean scores of boys and girls on the Interest attitude subscales. (N=268)

Note. The horizontal line is the neutral mean score on the subscales.

These findings suggest research questions, some of which can be explored using the data base being prepared as a part of the "logical competencies" project. We can ask about the relationships of attitudes to types of activities selected, to other student characteristics, or to achievement. We can initiate studies to determine, by means of class observations, the relationship of what students do in classes to their attitudes. We can determine whether the above outcome is replicable by others not connected with the project.

The unique characteristic of Human Sciences makes it a valuable research tool. This curriculum and others have been developed over the past two decades. The have not lost their value as research tools, whether or not they survive in the marketplace. More importantly, we should learn from the examples I have cited that there is an important and necessary interaction among development, evaluation, and research. We should take every opportunity to utilize these interactions. When the next round of curriculum development begins, we should be more knowledgeable about how to do it. The intuition of creative scientists and science educators desiring to improve instruction was a sufficient condition for curriculum development in the past. If we couple development with research, that condition becomes necessary but not sufficient. Intuitive curriculum development will be surpassed by development based on knowledge that most scientists and science educators do not now possess.

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PROJECTS THAT INTEGRATE SCIENCE EDUCATION RESEARCH AND DEVELOPMENT: BENEFITS OF INTERACTIONS AND COSTS OF MISSED OPPORTUNITIES

Mary Budd Rowe
University of Florida
Gainesville, Florida 32607

When Dr. Mary Budd Rowe was on the faculty of Teachers College, Columbia University, she began her research on a teaching variable, "wait-time," research that has brought her awards and recognition for significant findings in the field of science education. Her most recent award, the Robert Carlton Award of the National Science Teachers Association (1981) also mentions "her outstanding leadership in putting research into practice at all levels of science teaching," a factor which makes her uniquely able to speak to her present topic. Dr. Rowe is currently Professor of Subject Specialization Teacher Education at the University of Florida, Gainesville, but from 1978 to 1980 she served as Program Director of the Research in Science Education Program of the SEDR Division of NSF. She was awarded her Ph.D. in Science Education at Stanford University, and was a Post Doctoral Fellow at both Stanford and New York University. She is the author of several books and many journal publications, and is also a frequently sought consultant on science education.

Science is the central enterprise of the 20th century. Still, virtually anywhere in the world that you might stop to inquire, science means almost nothing to the man on the street. Yet its impact on him is growing. While development of new science and technology programs at all levels is going on at a moderately low level, until recently there was no research agenda to help us find out what we must do to make science and technology more learnable and more useful to people generally. The lack of a research agenda is akin to taking pot shots at the moon in a space program which was run on trial and error instead of research. We seem to know enough not to do that in space science. We ought to know enough to mount a good research program in science education.

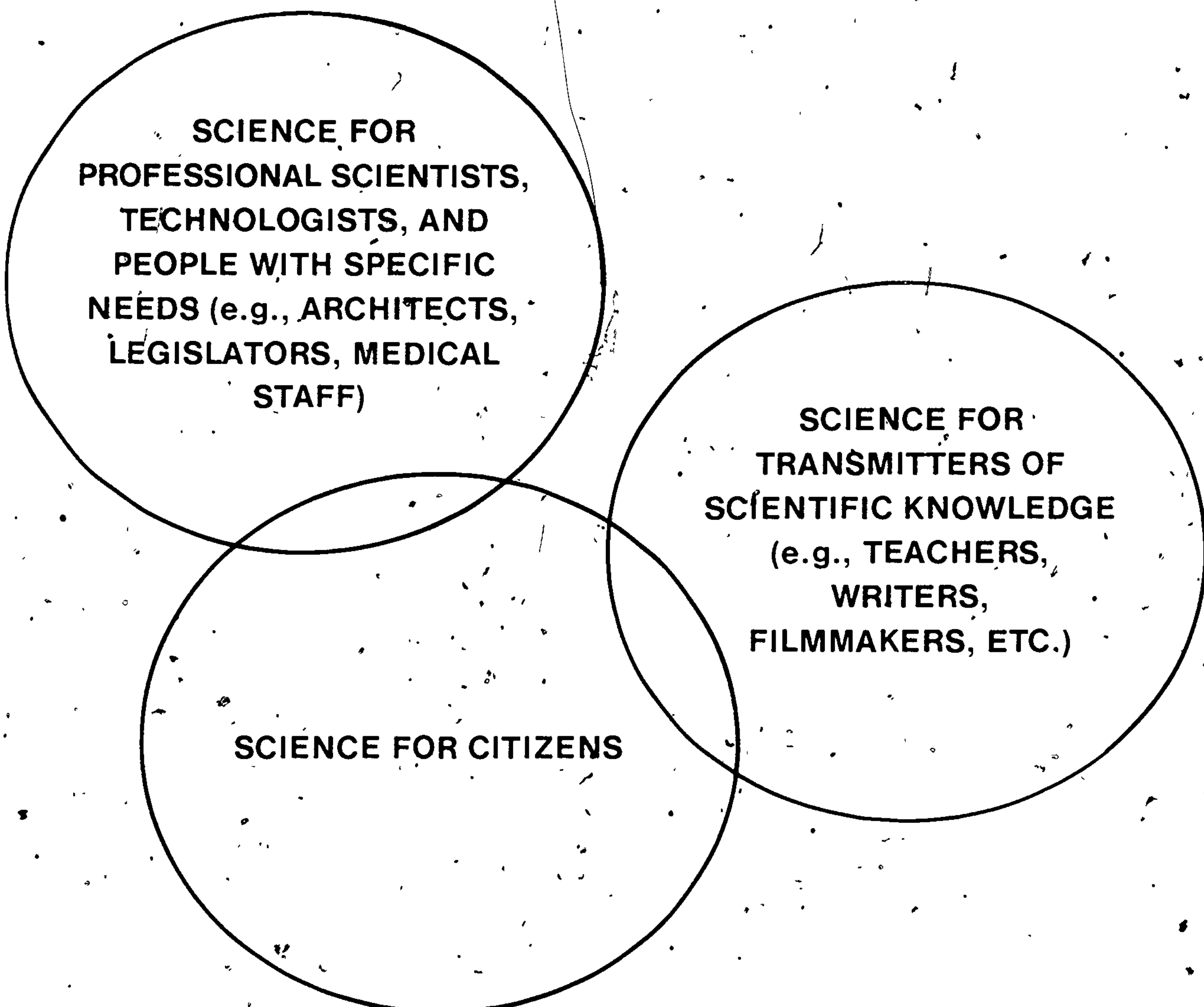
Decisions as important as those mankind must make today are never simple. Each one has enormous ramifications, all of which must be reasoned through and evaluated against the social fabric of our times--and in the light of our imaginings about the kind of future we want for ourselves and for our children. One thing seems clear: the decisions we make now help to shape the kind of future we will have.

We have some research on learning science under way now and some which is completed that should be useful in program design. The problem is to get it put into use.

Very few major decisions are simple. Instead, they usually set off a chain of events, each of which must be evaluated to determine its effects. For instance, if you find ways to improve the general health of a population, you increase its life span. Out of some apparently simple decisions, such as to make a new kind of hybrid rice or corn available to some region and to provide a few medical services, can come just a small change in the level of health and fertility that eventually thrusts new problems on a people. More people survive longer. That means you must develop correspondingly larger systems for supplying food, removing wastes, and delivering education. Living space must be reevaluated, as must the conditions for housing. The nature of health care changes, particularly as the population of older people increases. The kinds of illnesses that develop tend to be long-term rather than short-term; as a result, the hospital facilities must be altered. The number of individuals carrying defective genetic information who live to reproduce increases, and so eventually the frequency of defective genes in the population at large increases. That can mean that a whole chemical industry must be developed to supply the chemicals which defective human systems fail to manufacture. Of course, political and economic changes will also occur in the society, bringing new questions to the forefront. In the face of all this complexity, it is easy to feel defeated--to give up or to give over our lives to the care of a special elite. A democracy that made such a decision would soon descend to some form of dictatorship. Instead we must choose to find increasingly effective means for helping a broad array of citizens to grasp major ideas related to science and technology and to put them to use in their personal lives as well as in their political and economic decisionmaking (see Figure 1).

The interface between knowledge and its application is not well understood. There is yet no science of application. At the stage where men could put knowledge to use--that is, at the interfaces between science and society--each system falls apart or, rather, proves inadequate. Because we understand too little of the forces acting across that interface and even less about how to marshal the energy of the various sociopolitical and educational systems to take proper advantage of technical knowledge, we accumulate knowledge but fail to put it to use. Some other countries are putting our knowledge to use more effectively than we are. Education seems to be the only major professional enterprise where the ultimate users are expected to take the research and to engineer products and processes themselves. The users are supposed to do their own engineering. That rarely works, either in education or in business, or in medicine.

Figure 1
The Science Needs of Each of These Groups Are Somewhat Different



There was one brief exception to this situation. During the sixties the National Science Foundation supported curriculum development and teacher education in the sciences at all levels of the formal educational system. It did not support, however, a concurrent research enterprise. Most of the curriculum efforts and the dissemination programs of that era proceeded unencumbered by more than cursory attention to anything that might remotely be identified as a research perspective. What research was done had to be conducted sub rosa, on the side, so to speak. There was among the people doing curricular work great enthusiasm, somewhat evangelistic in nature--full of good will, but course development and inservice programs were only peripherally informed by research or accompanied by research. The post-Sputnik era in science education had great promise. I believe its potential was not fully realized for lack of a parallel research program. What was missing was a belief in the utility of research among developers and trainers. There was, to be sure, some limited attempt to evaluate program and gather data on student performance. This effort was small, unenthusiastically pursued, and often discounted when it produced results developers did not like.

We are still paying for the lack of a research program in that era. For example, in the curriculum era of the sixties one very important frequently repeated and remarkable finding was ignored, in some cases suppressed, namely, that among elementary school children, the poor benefited greatly from the new programs. Nothing else has yielded such advances. Gains for middle-class youngsters, however, were far less substantial. Very little attention went to the study of the impact such programs had on different kinds of students with a view to improving their effectiveness for different user groups.

Similarly, at the high school level, a concurrent research program might have alerted us much earlier to the fact that the physical science/physics was reaching only a small percentage of students--and possibly actually depressing the long-term potential for learning physical science ideas.

To take still another example, arguments between scientists and engineers about what would be of most worth could have been addressed with research instead of rhetoric. We are still living today with problems the large-scale curricular and instructional efforts of the sixties were meant to cure. Physical science concepts are still something we do not know how to transmit effectively. The problem extends from the elementary school through to the university--consider the so-called killer courses, e.g., freshman physics and chemistry as viewed by medical students, or thermodynamics as seen through the eyes of engineering students. Would our situation be as bad as it is today if there had been a concurrent research program? I doubt it. The curriculum efforts created a natural setting for research. The research, in turn, would have had consequence for redesign and for better human engineering. Such needed research has been begun in the RISE program on a small scale. It needs support and collaboration between researchers and developers. (On occasion, a researcher moves into development and a developer begins relevant research. We would expect to see more of that in the future.).

So here we all are today in a situation analogous to the one we faced in the post-Sputnik era. Education in the sciences at most levels of schooling has slipped steadily. We are all here because we have an interest in the problem and a belief that we can contribute to a solution. We could do as we did then--flush another load of good stuff through the educational system and hope for the best while we argue. But we can no longer do that with a clear conscience--and neither can we repeat earlier ways blindly. We know better. In the long run, research properly joined to development saves money and time. Some of that research already exists, and the problem is to incorporate it in the development/design process. If development and trials of new science and mathematical materials and procedures go forward coupled with a research perspective, we will gradually learn how to do this job of effectively educating more people in the sciences and technology. The education directorate of NSF has taken first steps to help this process. This meeting and others which it has held in the past 2 years are examples; the emphasis is on cross-fertilization of ideas between developers and researchers. The SEDR group has published abstracts of grants; the program officers put people in touch with each other where it seems appropriate. I have been impressed by the predominantly inquiry stance of the participants.

There is much that goes on in modern science which is counter-intuitive. For children and adults to develop some science and technology understanding there has to be a break from past experience--a kind of distancing of experience. But past experience is very compelling--so in some sense one has to learn to operate at certain stages in a nonintuitive mode with respect to the concepts one seems to develop "naturally." Those who practice science as a profession understand those mental transitions--but for many people they create permanent barriers. Recently, we have begun to study the process by which the transistion from one way of looking at things to another can be brought about. The research on learning science suggests that there are many things in effective science instruction and in effective curricula which at first glance are also counter-intuitive. For example, teachers tend to give students an average of only 1 second to begin answers to questions. If they change that average time to 3 seconds or longer there are dramatic improvements in the extent and quality of student science reasoning. The trouble is that waiting 3 seconds seems like an eternity--it doesn't seem natural. We have been immersed in the educational pool for so long we think we know how to swim. In fact, we have been letting a lot of people drown because we have not understood the nature of the problem we are confronting or its complexity.

I believe that the limited research effort begun in the RISE program needs to be expanded. Research utilization requires special engineering. Just as in industry the research/development/utilization interfaces must be planned for--so should they be in science education. If they are not, our educational waste factor is going to rise to an intolerable level. Science education is not taking well in our country at this point in time. We ought to learn how to cope with the rejection process. Consider just a few problems which are still unsolved.

1. Physical science concepts seem to be particularly difficult to implant. Since they underlie so many technological and energy-related decisions, we need better understanding of the immune reaction.

2. The effective join-up of mathematics with science still escapes us. To put it succinctly, why is it that after many years of math training, students so often seem to have trouble in applying it in science?

3. We have a growing cadre of older working engineers and scientists who need to update, or often to acquire new knowledge in another field of science or engineering, as part of their work. Over 200,000 engaged in some kind of formal inservice training last year. What do we need to know about the older "expert" learner's problems in order to make the instruction efficient and effective? It seems clear that their situation does not correspond directly to that of the novice just entering that content area (e.g., a college junior taking vector analysis for the first time).

4. In what way can new technologies be used to help develop aptitude in mathematics and science? For example, with the multilevel management systems which are potentially available with some computers, we could present some of the large service courses, e.g., physics and chemistry and calculus with different dosages of applications problems drawn from the prospective career specialties of the students. No single professor has that kind of flexibility or breadth of knowledge. Would student survival rates increase?

5. What in school settings, media events, or hobbies, can help develop and maintain attention to science and technology?

6. Perhaps, most importantly, how does our fundamental belief in the future and what we can do with it, our sense of fate control, relate to our national investment in science education (see Figure 1)? Fate control orientations are a factor in scientific and technological productivity.

The vigor of science and technology in a country depends in part on which of two forms of fate control orientation predominates. Fate control refers to a pattern of beliefs about the world, one's place in it, and the effect one can have on it. Early exposure to science and technology instruction, both in and out of school, appears to have some consequence for the kind of fate control orientation that a person develops. To characterize the contrasting fate-control orientations, one might be called the "gambler's view" and the other be described as the "bowler's outlook." Low fate control people (the gambler view) think of the world as a great big game of chance in which they are at the mercy of powerful forces beyond influence. Low fate control people consider life to be full of unpredictable events and people. How things turn out is a matter of luck, sometimes good and sometimes bad (Figure 2). When faced with difficulties, they exhibit low task persistence. For them, long-term planning and goal-setting seem useless. In an essentially whimsical world, planning and the evaluation of consequences that might follow from various possible decisions makes little sense. For this reason, low fate control people tend to be now-oriented, focused on quick results that require little personal investment.

The alternative world view, high fate control, rests on the belief that how things turn out is at least partly related to the way one plans, acts, and evaluates consequences. High fate control people are more likely to think that events and processes are related to each other in patterns that can be put to use. They are more active, therefore, in seeking information when confronted by problems than are their low fate control brethern. In contrast to low fate control people, high fate control individuals believe that how they do things makes a difference in the kinds of results they get. Unlike their low fate control counterparts, who seem to have a kind of "no fault" perspective on themselves, high fate control people accept a much higher level of responsibility and accountability for outcomes.

High fate control individuals differ markedly from low fate control individuals of the same aptitude in how they interpret the world. Low fate control people act as if the world consisted of a collage of events with few connections between them, as though each event had sprung full-blown on the landscapes of their lives. But for high fate control people, events have roots and evolve by processes which one can discover and sometimes change. They are less likely to give up when faced with complex tasks or problems.

The proportion of each kind of fate control orientation in a society affects the vigor of science and technology growth in a country. Early exposure to science may have considerable consequence for the kind of fate control orientation which a person eventually develops. Generally a high fate control perspective is more suitable for science and technology growth. The <u>way</u> in which science instruction is carried out appears to be a factor in the form of fate control perspective which finally emerges.

Figure 2
Two Contrasting Fate Control Orientations

FATE CONTROL

LOW FATE CONTROL	HIGH FATE CONTROL
CHANCE - CAN'T INFLUENCE ODDS	CAN INFLUENCE ODDS
NO USE TO TRY - YOU CAN'T MAKE A DIFFERENCE	TRY THINGS - LEARN FROM EXPERIENCE
NO EVALUATION OF CONSEQUENCE	EVALUATE OUTCOMES AND USE INFORMATION
NOW ORIENTED: HERE AND NOW REWARDS	**FUTURE** ORIENTED: DELAYED REWARDS OK
LOW TASK PERSISTENCE	HIGH TASK PERSISTENCE
SCHOOL ACHIEVEMENT LOWER	SCHOOL ACHIEVEMENT HIGHER
PASSIVE	ACTIVE
POOR PROBLEM SOLVER	AGGRESSIVE PROBLEM SOLVER
SUSCEPTIBLE TO INFLUENCE	RELATIVELY RESISTANT TO INFLUENCE
"HOW I DO THINGS MAKES NO DIFFERENCE IN HOW THINGS TURN OUT."	"HOW I DO THINGS MAKES A DIFFERENCE IN WHAT RESULTS I GET."
GOAL SETTING IS IRRELEVANT	GOAL SETTING IS RELEVANT
DISPLACES RESPONSIBILITY OUTWARD	MAY BE EXCESSIVELY SELF-BLAMING

We need research that helps us understand how to help students join together <u>ways of knowing</u> and <u>action</u>:

1. How things work (description)

2. Why they probably work that way (explanation)

3. What must be done to make them happen in other circumstances (control)

To continue around the science cycle in Figure 3 to the <u>consequences</u> and <u>value</u> stages, what must we do to help students complete a cycle of science reasoning so that they will answer the questions below in a desirable manner (see also Figure 4).

1. Do I know what would happen as a result of implementing a given set of actions? (prediction)

2. Do I value the outcome?

3. Do I care enough to make the effort?

And so the cycle continues.

The completeness with which one moves through the cycle in different content areas is at least a partial determinant of the fate control orientation which young people will develop.

Social, moral, legal, economic, and political decisions once undreamed of are now required of us by the growing capabilities that science gives us to shape our destiny. How are we to make those choices? Can we make them in time? Clearly, the decisions are no longer simply medical or scientific (Figure 5). Whatever gap once existed between science and the body politic is gone. We need a vigorous basic and applied research program in science education to keep us from falling out of a democratic state by the turn of the century. To paraphrase an ancient Chinese philosopher:

> The pheasant has to take 10 steps to get a mouthful of food and 100 steps for a beakful of water. But it would far rather do that than be kept in a cage, for, though it might be treated like a king, it would not be happy.

Our task in a democracy is to teach our people how to live outside a cage. That is one purpose of our development and our research in science education. It is not to turn over our lives and our futures to the exclusive control of a small elite. We need a close union of research, development, and training.

Figure 3
A Science Knowledge, Application, Value Cycle Related to Strong Fate Control Development

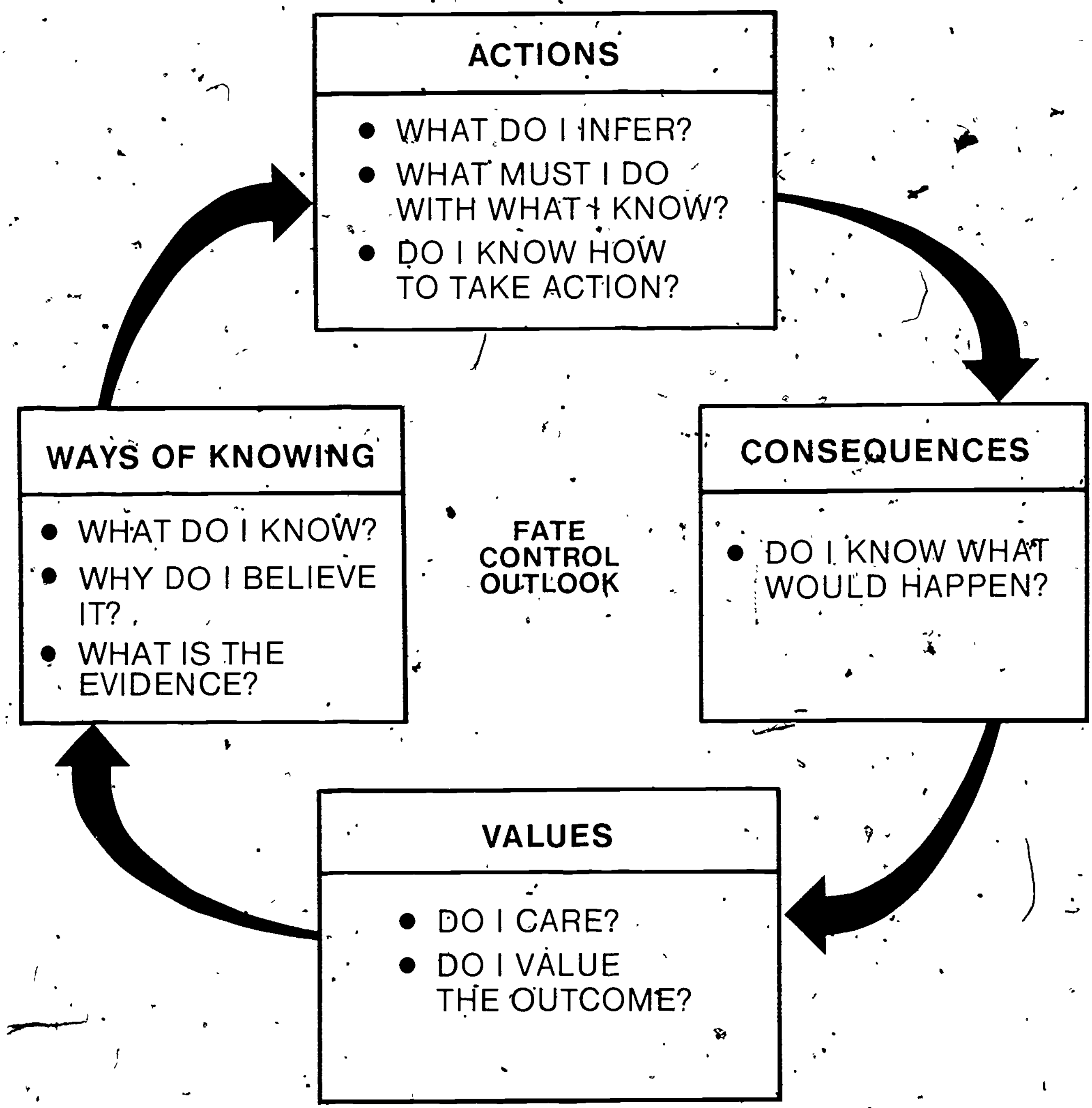
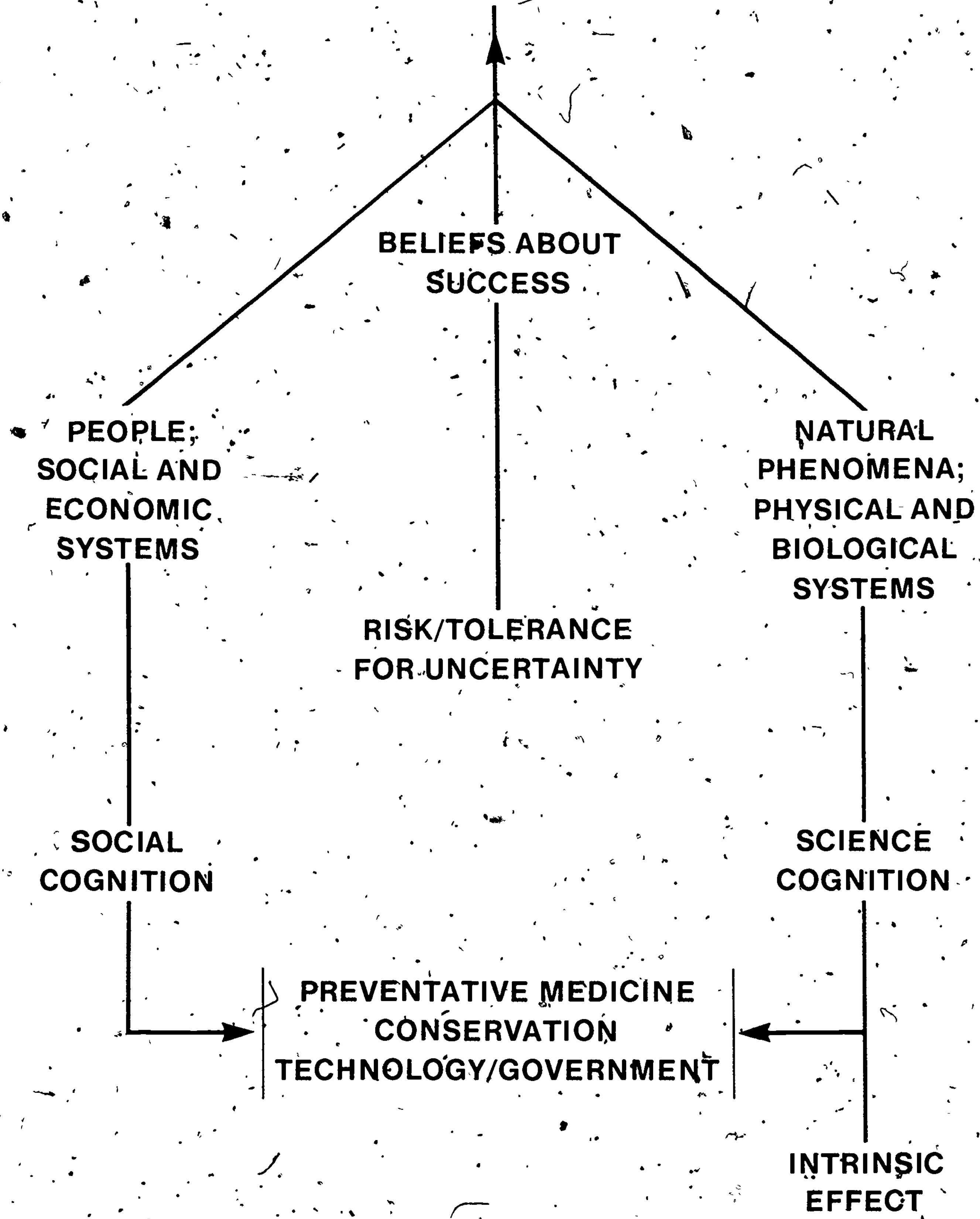


Figure 4
Questions Early Adolescents Ask Most Often

- WHAT KIND OF COUNTRY IS THIS?
- WHAT VALUES CONTROL ACTIVITIES?
- WHERE DO I FIT IN?
- DO THEY EXPECT ME TO SUCCEED OR FAIL?
- HOW MUCH EFFORT IS DEMANDED IF I DO WHAT THEY WANT?
- DO I HAVE THE ENERGY?
- CAN I GET HELP?
- WHAT HAPPENS IF I DON'T MAKE THE EFFORT?
- WHAT AM I UP AGAINST? WHAT'S THE COMPETITION?
- ARE THE CHANNELS OF SUCCESS WORTH THE EFFORT?
- WHAT DIFFERENCE WILL IT MAKE?

Figure 5

FATE CONTROL



WHAT SCIENCE/MATH EDUCATION RESEARCHERS SAY TO THE DEVELOPMENT COMMUNITY

Diane McGuinness
Stanford University
Stanford, California 94305

Dr. Diane McGuinness was awarded a Ph.D. degree in Psychology at University College, London. She had earlier earned her. B.Sc. degree in Psychology with First Class Honors from Birbeck College, University of London, as well as the B.A. degree in Music and English at Occidental College in Los Angeles. She is currently a Research Associate at Stanford University and a Lecturer at the University of California, Santa Cruz. Dr. McGuinness has written and spoken extensively on sex differences in cognition and behavior and brings considerable insight to her subject of what researchers in science and mathematics 'say' to the development community. Her remarks are most timely and throw light on what is involved in current science education practices.

With the imminent demise of the DISE and RISE branches of NSF a discussion of the modes of communication between these agencies now seems less imperative than the issue of the inability of the research and development groups to impress upon the government and the population at large the overall purpose and function of science education in this country. After reading the recent NSF report on the state of science education, and in reviewing the various project proposals currently funded, I directed my remarks at the SEDR meeting to the larger issues of the purpose of science, the nature of the communicative process, and the meaning behind the current mandate from the people toward a back-to-basics conservatism. These remarks, set out below, seem all the more relevant if SEDR is ever to rise from the ashes and assume its primary role in establishing and directing a policy for science education.

What is Research?

Science is a poorly understood concept, particularly in America. The image of the scientist is one that conjures up test tubes and gadgets surveyed by an impassionate introvert totally removed from the political, cultural, or humanistic aspects of the society at large. If science education were to do one thing well, it might be to dispel this stereotype.

Science means knowledge; but more than this, it promotes the scientific method. The truth behind the method is not that it is deductive or inductive or reductive, but that it is the only means we have of sharing experience directly. This kind of sharing, derived from imposing structure, attaching numbers, and creating reproducible events, allows the human race to proceed from fact rather than from opinion. This is not to say the method is infallible--but it is certainly more nearly so than opinion, and it is all we have.

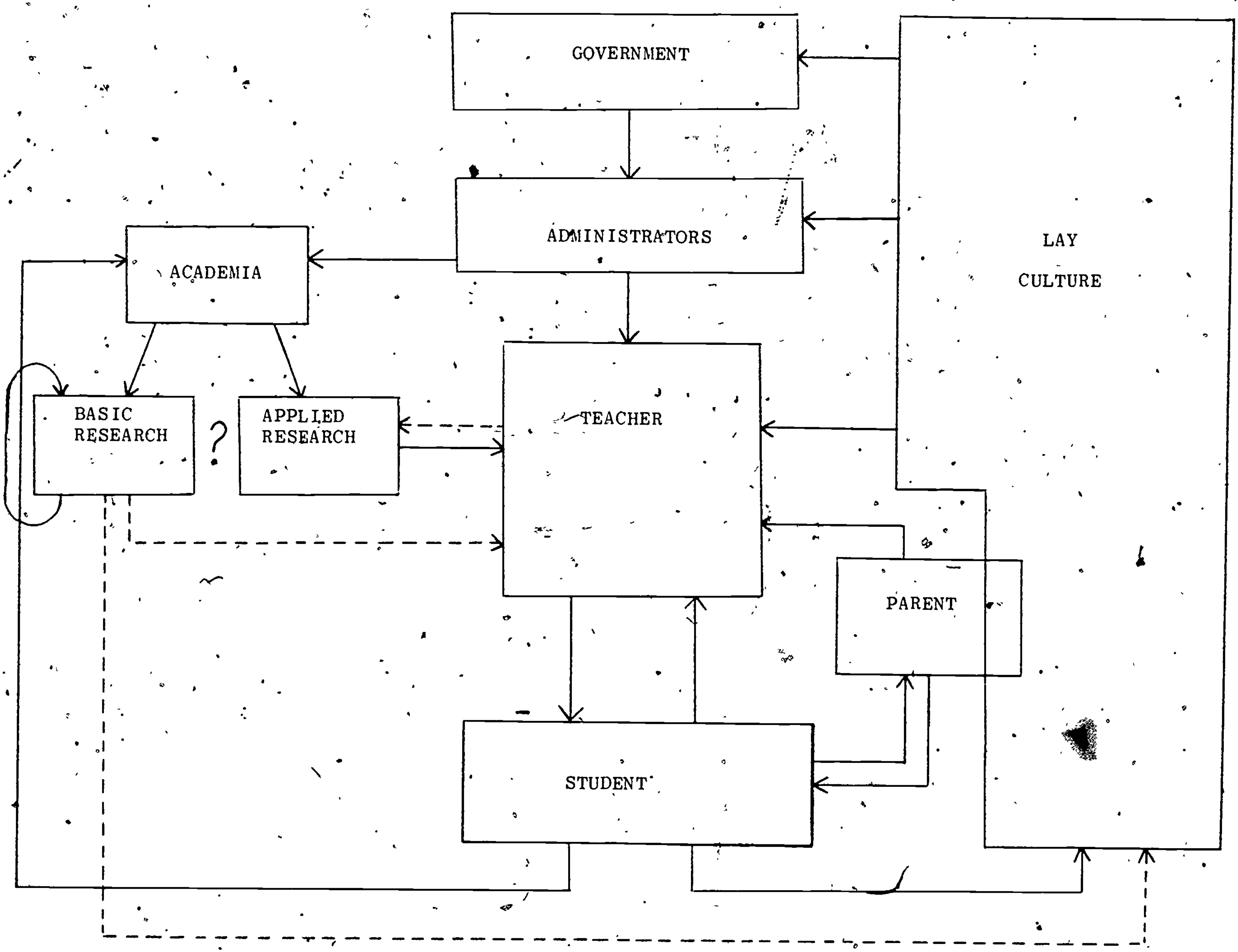
The significance of science education, and indeed all education, is that it allows us to be "led out" (e-ducere) from a private world of subjective viewpoints, rationalizations, and superstititions, to a clearer view of the nature of reality. This reality is not only to be found in the world of objects, but in the nature of emotions, the decision-making process, social organizations, and so on. Thus, the first major point is that the method of science, not its subject matter, is critical. Without a full understanding of the implications of this mode of thought, true education is impossible.

Scientists do research, which simply means they "look again." To re-look allows one to cast knowledge or events into a series of different frames or contexts and to observe the changes that occur. By attaching numbers to the changes, knowledge is made externally verifiable. This is the formal process of scientific research. But research has two further outcomes. The first is discovery, to find out what one least expected. Discovery initially stems from questions that begin, "What if?" What-if is the key to the entire learning process, but acting upon what-if questions is often the last thing a student is allowed to do. The second outcome of research is that as paradoxes are resolved, the questions change or become more precise. In all research the form of the initial question is often more important than the answer.

Who Finds Out?

The communication of research begins when an event or a process becomes reliably or statistically reproducible, even though an understanding of causality may be imprecise or lacking. We know that teaching makes a difference in the learner, even though the exact nature of learning may be unknown. The question for all those engaged in research, not only in education, becomes one of how to disseminate information where it will count most. A major point here is that while learning should rely on discovery, it should not require that each student rediscover the wheel. New data must be acquired and added to the existing body of knowledge. Somehow the educational process from an early age must incorporate a scientific mode of learning-for-oneself along with the more didactic mode of imparting existing information.

In the current state of affairs the communicative network of our educational system is much as depicted in the diagram in Figure 1. In this figure the solid lines represent the actual flow of information. The direction of the arrows provides considerable insight into the strengths and weaknesses of the system. First, it is obvious that


GOVERNMENT
ADMINISTRATORS
ACADEMIA
LAY
CULTURE
BASIC
RESEARCH
?
APPLIED
RESEARCH
TEACHER
PARENT
STUDENT

the maximum input is to the classroom teacher, but this fact, which could operate in beneficial ways, simultaneously illustrates the teacher's powerlessness. The information received by the teacher is often in the form of mandates and sanctions and may frequently be contradictory. But the true measure of their impotence lies in the teachers' sphere of influence: the only people who listen to their voices are their students.

Academics, on the other hand, have relative autonomy. They are immune from pressure from the lay culture and the direct intervention by parents, and simultaneously immune from the knowledge that these populations have to offer. Administrators, via government dicta, interfere only in terms of research funding and salary structure, and not inevitably.

But what of research? Here is the backbone of our culture, the foundation of our future heritage. As the diagram illustrates, research findings enter a closed feed-back loop in which only the researchers themselves inform and are informed. The question mark indicates a central problem which is addressed at this meeting. The communication process is restricted not only by specialism reflected in closed-circuit journals edited by the researchers who do the research, but by polarized attitudes on the part of the two groups. There is a cynicism among researchers that communicates an ivory-tower snobbery to those in the applied realm. This cynicism is reflected in the view that research data are too complex to permit the dissemination of information to anyone other than one's peers. One must of necessity "write down" to make the results appear more tangible and coherent than they really are. This same snobbery also invades the media when journalists or editors assume that the lay population are too unsophisticated to cope with anything other than the most simple-minded ideas.

Those in the applied realm tend to discount the efforts of research because it is assumed that the researchers are too remote from the real world and cannot relate their ideas to real problems. At the end of the line are the teachers, who, being totally removed from any information of mainstream research, find their classrooms invaded by zealous developmental enthusiasts who offer a brave-new-world technology or band-aid science with little regard for how the teacher is to cope. The situation is chronic and requires considerable rethinking for any improvement to occur.

New Lines of Communication

In the diagram, three avenues of communication (in dotted lines), perhaps the most crucial, are currently closed. First, it is obvious from the central position of the teacher that they should be a reliable and immensely valuable resource. To open the first avenue then, would allow input <u>from</u> the teacher to flow at least as far as the applied arena. This would entail not only suggestions to the

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developmental agencies of what is possible and where the constraints may lie, but a greater awareness on the part of developers of the dynamics generated by good versus poor teachers. In the recent NSF report on science education, it was stated that good science teachers were obviously to be found in the system, but that their aptitudes and styles were "too idiosyncratic" to provide a coherent model. This is another way of stating that it is too bothersome or difficult to determine the variables that combine to produce an effective educator. If those in the applied realm don't understand these dynamics, then there is little that can be applied! Table-model microprocessors are not the solution.

The remaining avenues are those that should connect the people engaged in basic research to outsiders. The first avenue must extend to the teacher, who, if informed of current knowledge in the fields of learning, problem-solving, and motivation, will be considerably more likely to feel confident in utilizing or applying suggestions from those in the applied domain.

Secondly, we need an informed lay population, because it is they who set the trends and open up possibilities in any democratic society. It has often been voiced that when communicating research to outsiders the message not only becomes oversimplified but can lead to misunderstanding or even havoc. In one sense this may be true, but information will leak out willy-nilly. If we allow these leaks to be transmitted by those in control of the media, this is a considerably greater disservice than if we ourselves communicate directly and repeatedly. If researchers could be bothered to write for the people, if only on occasion, the possibility of misinterpretations would be considerably lessened. After all, we educate the people; they should be trusted to read and understand what we write. The fact that academics don't trust the judgment of the people taught by those they themselves have trained is really a scathing indictment of our whole educational system.

The Conservative Mandate

Something clearly has gone awry. It is not only that Johnny can't read, but Jenny, as a college sophomore, can't spell, and Sam, as a senior, can't write a grammatical sentence. Everyone agrees that no science is possible without both literacy and numeracy. But this is not to say that we cast science aside in order to learn to add and subtract.

The mandate from the people is misunderstood. Science, the arts, exploration, the process of becoming self-aware are seen as frills only when there are no skills. The populace has seen money poured into education but found no return on the investment. And the people are justified in this grievance. If we were given a golden opportunity, how was it squandered, and where, and why?

The fact that we as a nation and as educators need to comprehend is that no education is possible without discipline and techniques. The drill that begins at dawn on the football field produces an excellent athlete. But if teachers must aim only to entertain, this puts the classroom in competition with television and film. Skills are not acquired in passing or by osmosis. Repetition and hard work are required.

With this realization, voiced in the dissatisfaction of parents and teachers alike, science should not be seen as peripheral but central to the aims of education. The process of verification, the function of numbers, the need for proof, can follow directly and in parallel with the acquisition of numerical and logical skills. Science should not be seen as something tacked onto the educational process at some remote point, but as an early and fundamental tool for learning.

And we need research. We are at the frontier of understanding how children learn. We need still to discover which cognitive strategies exist, and to determine which of these strategies lead to special talents. We, as researchers must shed our reticence and begin to communicate, to disseminate facts to both educators and lay people alike. A classroom without information from relevant research, without the full comprehension of the power of the scientific method, results in the perpetuation of ignorance. For in this setting anyone can be right, even though everyone is wrong.

NEW HORIZONS IN EDUCATIONAL DEVELOPMENT

Jack Lochhead
University of Massachusetts
Amherst, Massachusetts 01003

Dr. Jack Lochhead, Ed.D., University of Massachusetts, Amherst, is currently Assistant Dean for Basic Cognitive Skills Instruction there. He has served as a project director for a cognitive development project with both NSF and FIPSE, always pursuing his compelling interest in the techniques used in problem-solving. Dr. Lochhead is the author of numerous articles and seminar presentations. He has conducted many workshops, and he is about to have his third book published. From his remarks that follow, we find that he is currently greatly involved in the task of learning about "unlearning."

The message that I as an educational researcher would like to bring to those of you--and the half of me--involved in educational development is that the next decade is going to be an incredibly exciting time for development. Educational theory and practice today are roughly at the stage where physics was about 1915. Twenty years ago the prevailing view was that there was nothing more to be done in educational theory. The basic mechanisms of learning were thought to be understood, and the future of education lay in refining existing approaches. Curriculum development was seen largely as a process of updating the knowledge base and clarifying the explanations. New technology could be employed to improve the presentation and to inspire the students' (or was it teachers'?) interest. But no fundamentally new modes of learning were envisaged. Education was a process of passing facts from those who had them to those who didn't, and pedagogy was the art or science of packaging those facts.

In 1900, physics underwent a revolution. The predictions of those who had claimed it was dead proved premature. At first, new and puzzling phenomena were observed. Then, entire regions for investigation, such as subatomic physics, opened up in areas that had previously not even been imagined to exist. The theories of relativity and quantum mechanics challenged not only the basic laws of physics but defied common sense and fundamentally altered man's concept of knowledge. It was no longer possible to view the scientist as a passive observer, for the actions and the reference frame of the observer could no longer be separated from the phenomena recorded.

These theoretical breakthroughs led to a complete reconceptualization of science and spawned an unprecedented series of technological breakthroughs in the 1930s, 1940s, and 1950s. These scientific developments have completely reshaped our world.

I foresee similar developments in the next decade in education. The new theories of cognitive science are establishing the base for revolutionary changes in educational practice. Previous behaviorist theory denied us access to the processes of thinking and learning, much as classical physics denied knowledge of the subatomic world. Modern cognitive psychology, on the other hand, is the tool we need to change not just the responses students give to our questions but, far more importantly, the processes they use to generate their responses. As in quantum mechanics, there are two schools of cognitive science. The computer modeling approach seems to offer some of the power of Heisenberg's matrix algebra, while investigations using Piagetian clinical interviews develop the types of intuitive knowledge more often associated with Schrödinger wave mechanics. It may take another decade to reconcile these two theories, but that should not delay instructional developments. Failure to combine the Heisenberg and Schrödinger formulations certainly did not slow the application of quantum mechanics.

It is always risky, if not imprudent, to summarize the essence of future breakthroughs without the benefit of hindsight, but let me be foolish enough to try. What I see as critical in the new cognitive science is the recognition that knowledge is not an entity which can simply be transferred from those who have to those who don't. To reiterate the point which Ernst Von Glasersfeld made so eloquently last night: Knowledge is something which must be constructed by each individual learner. Contrary to the popular idiom, it is not a torch which can simply be passed from hand to hand. This view of knowledge as an individual construction is inherent in both the computer modeling and Piagetian perspectives and is usually referred to as constructivism. [See Von Glaserfeld, 1979, for a more detailed exposition.]

Fred Reif has succinctly summarized the constructivist view with the following descriptions:

> The process of education can be viewed most simply as one in which a novice is operated on by a process known as education to transform him or her into an expert.
>
> (expert) ⟵ EDUCATION **X** (novice)
>
> Or in Dirac notation:
>
> $\langle expert \,|\, education \,|\, novice \rangle$.

The point of this simple analogy to quantum mechanics is that the effect of the operator, education, crucially depends on the initial state of the novice. There are three separate entities involved: the expert, the novice, and the transformation. Each must be understood if we are to have a complete theory.

Recent research sponsored by the National Science Foundation's program for Research in Science Education and by the National Institute of Education grants has begun the process of describing novice and expert states. In physics there is the work of Champagne (1979), Chi (1980), Clement (1980), Gr[illegible] (1979, 1980), Larkin (1980), and McDermott (1980); in mathematics, Papert (1980), Schwartz (1980), and Steffe (1980); in general science, Hawkins (1980), Karplus (1979), Lawson (1979), and Renner (1977); in genetics, Tolman (1980); and in chemistry, Gordon (1980). There are dozens more who ought to be mentioned, but this is not the place for a review.

While the all-important operator, education, has received rather less attention, Fred Reif is now developing tools for more precisely measuring the effect of its individual components (Eylon and Reif, 1979).

A great deal more needs to be done, but there is more than enough theory and data to keep educational developers busy for quite some time.

Let me skip now to some specific issues which constructivist theory poses for educational developers. I have picked five, more or less at random; there are many others I could have chosen instead.

The first is unlearning. Novices never come to a subject with a blank slate. They always assimilate what they are told and shown to what they already believe. In physics, for example, Newton's laws are assimilated with common sense physics in which all motion requires a driving force. The incompatibility of the two systems exists only in the expert's head, not in the novice's. Teaching experiments conducted by myself and many others have shown that it is exceedingly difficult to make students unlearn the "motion implies a force" construct. Fortunately, I just learned yesterday from Jim Minstrell that after years of trying, he has finally come up with an instructional operator that does this effectively for nearly 90 percent of his students. I am hopeful that analysis of Jim's method may help us understand how to develop similar operators for other transformations. Perhaps it can even feed back to basic research and help us begin to formulate a cognitive theory of unlearning.

A second issue involves the construction of intermediate states. Since novices must construct their own knowledge, they must pass through levels of expertise which are neither novice nor expert. Fischer and Brown (1977) have described this problem using the example of ski instruction. One effective method is to provide the novice with short skis. The result is not skiing in a purist sense, but it is an effective bridge to expert behavior. As teachers, we may want to bring our students to believe in incomplete, misleading, or incorrect theories. This has been the history of scientific theory, and there is every reason to believe it may be the most effective path for novices to follow. Developers must determine which easily accessible intermediate states form effective bridges to expert performance. These investigations will be complicated by the recognition that the search involves the intellectual lives of students. If an intermediate state turned out to be a side track rather than a bridge, learners might not easily return. But we must not be put off by the naive notion that current methods are any less dangerous.

The third issue I would like to consider is error. We need to provide students with ample opportunity for error, because it is only by making (and recognizing) errors that real conceptual learning is possible. The batteries and bulbs experiments which Arnold Arons (1977) describes in his text are excellent examples of how this type of curriculum can be managed. We need a great deal more similar material.

A fourth point concerns reflection. John Dewey (1933) claimed that the entire purpose of higher education was to produce reflective thinkers, people who could view and critique their own reasoning. Students can build their knowledge structures more effectively if they are given the chance--compelled--to examine their thoughts and those of others. We need curricula that encourage students to say what they think, especially when their thoughts are at variance with what we wish them to be. The dilemma here is how can we get students to share their ideas without deserting our responsibility to lead them beyond their current conceptions. If we constantly close such discussions with an authoritative statement of truth, we will quickly stop all student reflection; if we don't, we may validate ignorance.

My fifth and final point is a pet peeve of mine and really does not belong with the others. Yet, in these times of economic restraint I feel it is important to make it. We must not get carried away with buying expensive technology for its own sake. Complex machinery often serves to separate students from the phenomena they study. An automatic electronic eye stopwatch may allow for great accuracy, but to the novice it mystifies what might be clearer if a stopwatch, sand clock, or metronome were used instead. A brief anecdote may help to illustrate the problem. My parents had a free checking account in a small Vermont bank long before free checking was a common practice. One day they received a letter from the bank stating that in order to modernize their service the bank had installed a computerized checking system, thus there would now be a 25-cent charge per check. I happen to agree with Seymour Papert (1980) that the right use of technology can solve many of our educational problems. But finding the right use will not be easy, and we need to avoid buying devices simply because they are there.

Perhaps a concrete example can best summarize this talk. John Clement, Jim Kaput, Judy Sims-Knight, Steve Monk, Elliot Soloway, Peter Rosnick, Ron Narode, and I have been studying an apparently simple problem (Clement, Lochhead, and Monk, 1981). If you ask calculus-level college students to write in English what the equation A = 7S tells them, it turns out that about 70 percent interpret it backwards. These students are skilled in algebra, but they are in an intermediate state between novice and expert. Furthermore, it does little good to tell them the correct answer. Peter Rosnick (1980) gave calculus graduates the statement "There are six times as many students at this university as there are professors" and told them the correct equation for that statement was S = 6P. He then asked them what the letters S and P stood for. Nearly 25 percent said S stood for professor.

Getting students to unlearn even simple misconceptions is exceedingly difficult. We have had some success in teaching equation-to-English translation skills by giving students the opportunity to err and to notice their errors. If students are asked to write a computer program (no computer is needed) rather than an equation, far fewer make the reversal error (Clement, Lochhead, Soloway, 1980). When they are given a series of alternating exercises--write an equation, write a program, write an equation, etc.--they usually, after several cycles, notice the difference between their algebraic answers and their programming solutions. At this point, according to our experience, they recognize that the program is correct and revise their algebra. Further discussion and reflection on the reasons for their error helps solidify their learning. Unfortunately, the situation is a great deal more complicated than I have made out, and the instruction only works in certain cases. But the basic points are these. First, there is a serious hole in current instruction that is not apparent unless you look carefully in a manner the old educational theory would not have seen a need for. Second, the hole cannot be patched by simply handing students the correct information. Third, the job of developing appropriate curriculum materials will require a serious joint effort between researchers and developers that recognizes the constructive role of the student. Fourth, and finally, success in this endeavor could totally revolutionize science education. As things are now, 80-90 percent of college-level students studying mathematics don't really understand 9th grade algebra, but the curriculum of nearly every field assumes that they do. What miracles of learning might occur if they actually had the mathematical background we have been assuming?

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INITIAL INSTRUCTION IN ADDITION AND SUBTRACTION: A TARGET OF OPPORTUNITY FOR CURRICULUM DEVELOPMENT

Thomas P. Carpenter
University of Wisconsin
Madison, Wisconsin 53706

Dr. Thomas P. Carpenter has published as author or as co-author almost fifty professional papers having to do with pre-college science education, principally in the field of mathematics. He has taught mathematics at both the secondary and undergraduate levels, and has been a professor of curriculum and instruction at Boston University and, since 1975, at the University of Wisconsin at Madison. Two of Dr. Carpenter's chief interests, which are closely interrelated, are exploring how children learn mathematics and encouraging the development and the adoption of curricula that build upon the strategies that children themselves seem to develop for the solution of problems. Dr. Carpenter took his bachelor's degree in mathematics at Stanford, his master's from San Diego State University and his Ph.D. in Curriculum and Instruction from the University of Wisconsin.

In a recent issue of the Educational Researcher, Phillips (1980) provides a pessimistic assessment of what research in education has to offer practitioners. He asserts that:

> Social scientists have not been able to discover generalizations that are reliable enough, and about which there is enough professional consensus, to form the basis for social policy. (p. 17)

Although such pessimism may be warranted for questions involving broad policy perspectives or the construction of comprehensive theories of learning, there are areas of research on children's acquisition of specific mathematics and science concepts for which there is broad consensus based upon a substantial body of consistent research results.

The area that I would propose as a potential target of opportunity for curriculum development is the acquisition of basic addition and subtraction operations. There is certainly precedence for developing programs in arithmetic on the basis of psychological research. One of the most sustained attempts to apply basic psychological principles to the design of curriculum is represented by the arithmetic programs developed in the 1920s and 1930s based on the work of E.L. Thorndike (Cronbach and Suppes, 1969). A number of more recent examples could also be cited.

The work I am referring to, however, is not based on principles of associationism or behaviorism. A number of recent investigations have approached the study of addition and subtraction from a cognitive or information processing perspective (Carpenter, Moser, and Romberg, in press). Although there is not complete agreement on all the details, and a number of issues remain to be resolved, there is general consensus that most children initially solve addition and subtraction problems using certain counting strategies. There is basic agreement regarding the specific strategies that children use and the general pattern of acquisition in which strategies become increasingly sophisticated and efficient (Carpenter, Blume, Hiebert, Anick, and Pimm, in press; Moser and Carpenter, in press; Resnick and Ford, 1981). It is also generally agreed that the strategies are currently invented by the children themselves rather than learned through direct instruction (Groen and Resnick, 1977).

Certainly there is a great deal left to be explained. However, from the perspective of potential implications for curriculum development, these details are insignificant compared to the disparity between what is known about how children solve addition and subtraction problems and current programs of instruction. An examination of current mathematics programs reveals that very little effort is made to build upon the informal knowledge of addition and subtraction that children bring to the learning of these operations.

Building upon children's informal strategies appears to offer a number of advantages over current practice. The more advanced strategies that children invent for themselves are more efficient and show more insight than the models of addition and subtraction that are generally included in the curriculum. Furthermore, some of the more sophisticated strategies provide a structure for organizing number facts that should facilitate retention and understanding (Carpenter, 1980). Finally, since children readily apply their invented strategies to simple problem situations, building upon these strategies would offer the opportunity to integrate problem solving more completely into the primary mathematics curriculum.

In examining the informal strategies that children invent to solve addition and subtraction problems, one is struck by their relative sophistication. Children are able to analyze and represent the structure of different problems in order to figure out how to solve them; and they are able to invent a variety of relatively complex strategies for solving problems for which they have no algorithm. Other research has clearly documented that by the age of 9, many children mechanically add, subtract, multiply, or divide whatever numbers are given in a problem with little regard for the content of the problem (Carpenter, Corbitt, Kepner, Lindquist, and Reys, 1980). Somehow in learning formal arithmetic procedures, many children stop analyzing the problems they attempt to solve. I would suggest that the transition from the informal modeling and counting strategies that young children invent to solve basic addition and subtraction problems to the use of the memorized number facts and formal algorithms they learn in school is a critical stage in children's learning of mathematics, and that part of older children's difficulty in analyzing and solving problems can be traced to the transition from informal problem-solving strategies to memorized facts and formal algorithms.

In short, initial instruction in addition and subtraction fulfills three basic criteria that I would consider critical for a target of opportunity for curriculum development:

(1) There is a clear consensus regarding major aspects of the acquisition of addition and subtraction operations which is based upon a substantial body of empirical evidence.

(2) There is a disparity between the way in which children solve addition and subtraction problems and the instruction commonly presented in mathematics textbooks.

(3) Initial instruction in addition and subtraction is a critical phase of the mathematics curriculum which may significantly influence the development of basic problem-solving skills as well as the understanding of basic mathematical operations.

Specifically how a curriculum should be designed to reflect our knowledge of how children acquire addition and subtraction operations is a complex question. Curriculum development is a great deal more complicated than taking a scientific conclusion and putting it into a useful package (Cronbach and Suppes, 1969). From the same knowledge base that has been accumulated regarding the acquisition of addition and subtraction, a number of different programs might be developed based on different assumptions of how cognitive research should be translated into practice. For example, one might attempt to directly teach the most efficient strategies or the strategies used by the best students. Alternately, one might base instruction on the most elementary strategies that could be understood by all students under the assumption that the better students will invent the more sophisticated strategies themselves. One might even argue that current programs are appropriate since invention obviously occurs in spite of them.

Although the basic research that has been completed on the acquisition of addition and subtraction does not clearly suggest a specific program of instruction, it does provide some insight into viable alternatives for selecting and sequencing the content of instruction, and it provides a basis for evaluating the effect of instruction. I think this last point is important. The difference between current research and that of Thorndike is not simply that it arrives at conflicting conclusions. It proposes a fundamentally different way of looking at children's learning. This needs to be reflected in program development and evaluation. It seems clearly inappropriate to develop programs based on the careful study of children's processes and then simply evaluate the products of instruction.

We need to specify assumptions about how instruction could be related to children's informal addition and subtraction strategies, design instruction based on these assumptions, and evaluate the effects of this instruction using the basic techniques developed in the research programs. In other words, we need to evaluate the assumptions that link the theory to practice (Glaser, 1976; Phillips, 1980). For example, we know relatively little about the effectiveness of programs that reflect the sequence of development of basic science and mathematics concepts in children. We could develop and evaluate instructional programs based on the linking premise that instruction should reflect the sequences of acquisition of basic science and mathematics concepts that we have observed in children. I do not believe, however, that a basic premise of this nature can be answered in general. I think that the best we can hope to accomplish is to demonstrate that a specific program based on a specific set of premises produces certain kinds of learning. I think that, at best, we may arrive at some general conclusion regarding which assumptions are most productive as starting points for development.

What this suggests is an integration of research and development. Such an integration has as much to contribute to basic research as it does to the development of instructional programs. Cronbach (1975) has observed that "We cannot store up generalizations and constructs for ultimate assembly into a network" (p. 123). In other words, conclusions in social science are often not absolute. This is clearly reflected in research on addition and subtraction. Although research on addition and subtraction has produced consistent results, it is not clear that these results represent absolute truth. Most of the research on addition and subtraction has been carried out with children who have been exposed to essentially the same mathematics curriculum. If major changes are made in the curriculum, it is not clear how this will affect the patterns of acquisition that have been observed.

Finally, reflecting Cronbach's (1975) conclusion that knowledge in social science is not absolute, I would suggest that it is inappropriate to believe that we can attain complete understanding in an area and develop the ultimate mathematics or science program. I don't think that research and development of curriculum operate like, say, the development of a polio vaccine so that we can say, "We have done that; now it is time to answer another question." I think that the best we can hope to accomplish is to develop a curriculum that provides a reasonably good fit with our current understanding of how children learn science and mathematics.

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CURRENT TARGETS OF OPPORTUNITY--WHAT SCIENCE/MATH EDUCATION DEVELOPERS SAY TO THE RESEARCH COMMUNITY

Howard D. Mehlinger
Indiana University
Bloomington, Indiana 47405

While most of Dr. Howard D. Mehlinger's teaching has been in the Midwest, principally at Indiana University where he is Professor of Education and History, he has travelled widely in his professional life. On a grant from the Federal Republic of Germany he has visited institutes specializing in Soviet and East German studies and in political education; the U.S. Department of State sent him to lecture in Africa; and the Japan Society for the Promotion of Science has recently awarded him a visiting scholar grant. He has been a teacher of history (the Soviet Union, Western Civilization, World History for Teachers) as well as of education (Research in Secondary Education, Methods of Teaching Social Studies, and a seminar in Social Studies Education). The Social Studies Councils of several states have awarded him their Distinguished Service Award, and he has directed or developed proposals awarded by NSF, the then U.S. Office of Education, UNESCO, and the Ford Foundation among others. Dr. Mehlinger is the author or co-author of several books. He has served widely as a consultant and is a member of a great many committees, commissions, and boards having to do with his professional interests and responsibilities.

Our language contains many dyads--terms that seem naturally to go together: ham and eggs, liver and onions, hamburger and French fries, Procter and Gamble, Sears and Roebuck, and research and development. Alas, the rhythm of the language can be deceiving. Words that appear to go together do not always represent reality. After all, people often want ham without eggs or vice-versa; French fries do not always accompany hamburger; and certainly research and development frequently travel independent paths with little contact with one another.

To the extent that both research and development in education share the goal of improving practice in education, the field of education generally stands to profit from their closer cooperation. The time available does not permit an elaborate treatment of how closer collaboration between research and development might be accomplished. Rather, I shall merely indicate a few areas in which research could be of considerable benefit to developers and one or two institutional remedies for facilitating closer collaboration. Since all of my work has been focused on improvements in social science education, I hope that the audience will be tolerant to examples restricted to social science education.

Curriculum Research

The social studies curriculum of American elementary and secondary schools is 65 years old this year. If the social studies were a person, we would hold a party in his or her honor, present a watch in recognition of a lifetime of service, and retire him. Unfortunately, the social studies curriculum is not ready to retire, and the scope and sequence that was established 65 years ago by a national commission is likely to hamstring teachers and curriculum developers for the rest of this century, if not longer.

What we teach children in school today was determined largely 65 years ago when the country was vastly different, when less than 10 percent of youth completed high school, and when the overarching educational problem facing the country was how to accommodate and Americanize the vast stream of immigrants arriving from abroad. The demands for citizenship training led the schools then to cycle American history through grades 5, 8, and 11, and to provide civics and American government at grades 9 and 12. We did not then and do not today give much attention to the history and geography of other parts of the world. I know of no other modern industrialized nation in which the curriculum is so ethnocentric as is our own.

The problem of accommodating the social and behavioral sciences into the rigid, arthritic social studies curriculum is well known to all social science education developers. It is hopeless for an individual project to attempt a new scope and sequence; the forces of tradition are too powerful. The best one can do is to attempt to subvert existing courses; e.g., update the 9th-grade civics course with recent political science approaches, smuggle economics into American history, or provide a global studies perspective to the 7th-grade geography course. Amid all of the controversy surrounding Man: A Course of Study (MACOS) a few years ago, few commented on what was surely one of the principal reasons for its ultimate failure: MACOS was designed for 5th-grade students and the 5th grade is traditionally reserved for American history. Once the novelty of MACOS disappeared, it was nearly inevitable that the majority of schools would return to teaching about Indians, settlers, and American heroes at grade 5.

Frankly, curriculum development in the social sciences will continue to be constrained so long as we remain saddled with the current scope and sequence. We do not need studies of what the existing curriculum is; we have all of the research of that kind that is required. What is needed is a mix of empirical and policy-oriented studies aimed at producing a new scope and sequence that are more in tune with the time in which we live, with the logical development of subjects children should study, and with the psychological development of children.

Since establishing the scope and sequence is as much a political process as an intellectual one, an acceptable scope and sequence will not be achieved by a few scholars laboring on their own. The investment in traditional patterns is too great. Nothing less than a national commission containing distinguished Americans from many sectors of society is required. A national commission sets the existing curricular pattern; a new national commission will be needed to bury the past and start one or more new curricular patterns for the social sciences.

Providing details for how such a commission might be organized and conduct its work would exceed my time today. Nevertheless, there is no greater priority in the social studies today. And there is no better agenda for enlisting the joint efforts of researchers and developers.

Textbook Studies

The majority of curriculum development products ultimately take the form of commercial textbooks. Such products may be accompanied by a wide variety of ancillary material. While the design and format of the books may differ greatly from existing commercial products, developers cannot avoid the fact that textbooks provide the most assured route for reaching the greatest number of students.

We have some textbook studies. Some researchers have explored the importance of textbooks in instruction. Many studies analyzed textbooks for bias, focusing on the treatment of women and various minorities; others have sought evidence for textbook treatments of certain content themes and social science concepts. From these studies we know that textbooks are important in setting the instructional agenda and that nearly every social studies textbook has deficiencies from the perspective of one investigator or another. But there is much more to learn about textbooks and their use that would be helpful to developers.

How are textbooks used? It is rather remarkable, but developers guess a lot about how teachers actually use textbooks. What is considered a reasonable reading assignment? What use is made of illustrations, tables, charts, maps, and so on? Are "end-of-chapter questions" used; if so, what kinds of questions are most helpful?

Decker Walker at Stanford University is currently directing a project to explore how textbooks are used in three or four high schools in contrasting communities. The aim of this study is to relate study patterns, textbook features, and teaching practices to student performance on examinations. Studies of this type might contribute importantly to the design of better textbooks.

How is textbook content determined? Policy studies indicating how decisions about textbooks are made would also be useful. Nearly every developer can offer personal accounts--some humorous, others tragic--of experiences with textbook publishers (editors, salesmen) and textbook adoption committees at state and local levels. As Frances Fitzgerald pointed out in her book America Revised, decisions regarding what goes into a textbook are a matter of political judgment as well as intellectual talent. Studies are needed of textbook adoption processes and the factors that influence editors.

What can we learn from others? And finally, we have much to learn from other countries. It is remarkable just how ethnocentric the American educational community is. Certainly some American educators have a certain noblesse oblige attitude that leads them to share America's experience with other countries, but there is remarkably little curiosity about educational practices in other nations. The possible exception to this rule is interest in England, perhaps because Americans, who are notoriously deficient in languages, can visit English schools and understand what is taking place without the use of interpreters. Since World War II, under UNESCO auspices, many nations have engaged in binational and multinational textbook studies; the United States has remained aloof from most of these.

Since 1977, my center has hosted two cross-national studies of textbooks, one involving scholars in the United States and the Soviet Union, the second engaging American and Japanese scholars. The results have far exceeded our original expectations. We have much to learn from other countries in the manner in which they organize their curricula and in the ideas they present to students. No American business could hope to survive with the kind of arrogance we have displayed in education. International and comparative research in education could strengthen efforts to improve education in this country. We might begin by undertaking textbook studies.

Comparative research on textbooks faces a severe handicap. At this moment there is no adequate library to support comparative textbook research. In the social sciences the only suitable library in the world is the Georg Eckert Institute in Braunschweig in the Federal Republic of Germany. We are in the process of establishing a comparable library for social science education at Indiana University, but presumably similar textbook libraries are needed for mathematics and the sciences. Someone should begin to establish libraries in these fields as well.

Naturalistic Studies of Classrooms

We have enough studies of what happens to curriculum products upon their arrival in classrooms to know that the products change during use as much or more than does classroom practice. Moreover, the direction of instructional change is often quite different from that predicted or desired by the instructional developer.

Of course, it has long been obvious to developers that their ideas would work differently in practice from how they imagined they ought to work from the perspective of their offices. What some developers have not fully comprehended or appreciated is that pilot schools are also exceptional settings and that what occurs in classrooms with volunteer teachers committed to the project may not represent at all the settings in which the materials will be used later.

Intentionally, we have worked curriculum development in primarily one direction--from the developer to the teacher--while accommodating as many of the predictable variables as possible. For the most part, we have not worked development from the other direction--teachers informing developers of what is needed and accommodating development to practice. Resistance by teachers to force-feeding from developers was one of the primary motivations leading to ESEA Title III projects and "teacher centers" which feature teacher-development of curriculum products. This has generally led to greater teacher satisfaction and weaker products.

Naturalistic research on what good teachers do with their own self-generated materials and commercial textbooks might produce clues for how developers could devise products more acceptable to a greater number of teachers. Such products might "fit" the classroom setting and the teaching style of existing teachers better than previous products, thereby making fewer demands on teachers and leading to greater acceptance.

Organizational Responses to Research and Development Needs

The organizational implications for the few examples of needed research cited here range from the establishment of a national commission, to the creation of international textbook libraries, to scholars conducting on-site classroom instruction. There are some common elements, however, that might be recognized:

1. Some of the required work demands sustained attention over several years and reliable funding. The work of a national commission or the establishment of a textbook library cannot be accomplished by a 1-year grant.

2. Some of the work calls for a continuing base of operations. While it is desirable to widen the net to include people who have not previously been active in research and development, this advantage has to be weighed against long-term institutional commitments to a line of activity. Government and private funding agencies, especially during periods of shrinking resources, need to assess carefully what is likely to continue after a particular project has expired.

3. Nearly every important task confronting research and development in social science education demands teams of people embracing a range of skills and experience. Research divorced from development is merely another obstacle to overcome before the research findings seep back into development practice. And research and development divorced from classroom practice is certain to produce impractical results. This does not require that researchers, developers, and practitioners must all be based at the same sites, but the communication network cannot be casual and only occasionally closed. Few models exist of close, continuing cooperation among developers, researchers, and practitioners. Those that occur should be studied and extended; new models should be devised.

It is very "American," I guess, to tolerate--even to encourage--individual entrepreneurism in education. But there is also enormous waste in such a system. We have witnessed more than two decades in which development and research occurred largely independently of one another, a period in which practitioners have largely ignored both processes. It is time we learn from that experience and bring the three elements into closer coordination for the improvement of practice. We can become more cost effective--that too is very American.

CONVERSATIONS BETWEEN RESEARCH AND DEVELOPMENT: WHAT IS THERE TO SAY?

Kristina Hooper
University of California-Santa Cruz
Santa Cruz, California 95053

Dr. Kristina Hooper is an Assistant Professor of Psychology at the University of California at Santa Cruz with a bachelor's degree from Stanford University and a doctoral from the University of California, San Diego. Her areas of interest include cognitive psychology, architecture and urban planning, environmental simulation, imagery, and computer graphics in mathematics education. In these many fields she has either taught, been a consultant, performed research, or directed projects. She has also given talks at M.I.T., the University of Massachusetts, Cornell University, the University of Wisconsin and in several California academic and professional settings. In addition to the writing of several research papers and chapters, she has prepared a film, some videotapes, a museum show, and two radio programs for the BBC.

General folklore and public policy suggest[1] that research and development are co-partners in the business of the advancement of concepts and products. Researchers find themselves funded for work leading to the development of new valued products and programs. Developers realize that they should base their work on the results of research efforts and that their developments will provide a focus for research long after they consider their project completed. And so the concept of a natural cycle of research leading to development, leading to more research and more development ad infinitum, is implicitly accepted in both the research and the development communities.

Yet anyone who has seriously considered research and development from the position of either a researcher or a developer on a specific project, or, better still, anyone who has worked on both research and development efforts, realizes that the cycle of research and development is not a natural one. Moreover, one realizes that the aims of research and of development are not even necessarily compatible.

Hence the question "What has development to say to research regarding targets of opportunity in science education?" is a bigger one than it seems initially. For, in addition to addressing the goals of science education, it inherently addresses the general issue of the relationship between development and research, and it does this while simultaneously asking that targets of opportunities in science education be identified.

Given the denseness of this question, let's begin slowly. First, let's build a simple model of the world of the developer in science education, and then let's build a simple model of the world of the researcher. Then let's consider the general interaction of these two groups of individuals, and let's list a number of general things the developer has to say to the researcher. And then, to complete our consideration, let's explicitly discuss the role of a cognitive scientist such as myself in research and development in science education, illustrating the earlier discussion with examples from my own projects on the development of visually based courses in college mathematics.

Development Efforts

Development efforts require a product, a product that is workable, that solves a particular objective. The development of this product--be it a computer laboratory to teach physics or a set of videotapes that explain concepts in precalculus--requires the coordination of a range of expertise to solve particular problems. Experts in science, education, and communication media must work together to produce products that are sophisticated in all of these areas. And in this working together these experts must quickly and intuitively make a range of decisions, often without all the information required to guarantee the best decision. Much like the inventor and the artist, then, the developer coordinates practical and conceptual concerns to mold what is known in a situation to solve those problems that have not yet been systematically addressed. For even when research literatures are available, these literatures typically address general principles rather than specific instances. Decisions must be made to tailor the general principle discussed in the literature to the situation at hand.

When a development effort is completed, the decisions along the way are considered effective if the product satisfies the constraints of the situation. It doesn't particularly matter why the product is successful, and it doesn't matter that a range of alternative scenarios would have generated other successful situations. What matters is that the task is completed, that the product is judged successful by the relevant individuals, and, to a lesser extent, that the participants have developed skills that will enhance the probability of their success in similar future endeavors.

Research Efforts

In comparison to development efforts, research efforts on the surface seem to necessitate a primarily scientific approach rather than one that is artistic or pragmatic. It matters to the researcher not only that something works but also why something works. In addition, rather than solving one specific problem in the best way, the researcher must generalize from one set of observations and situations in order to make predictions about another situation. Unlike the developer, the researcher must consider the effects of alternative decisions in problem solving, and assess the fundamental differences between these in a theoretical framework.

To accomplish all of these objectives, the researcher carefully defines the domain which is to be the subject of concern, rather than tackling existing situations that have been deemed important. One doesn't investigate a particular curriculum as a researcher, then, but instead focuses upon a single attribute; for example, the communicative effectiveness of graphs. For the researcher to make any conclusions about the effectiveness of a particular strategy, the strategy must be carefully defined, as must the objectives for effectiveness. A research experiment must be defined in such a way that it can be replicated at another time or by other researchers. It cannot stand on its inherent worth like the development effort without attention paid to method, description, or theory.

Interaction of Development and Research

Researchers feel they are seeking truth. Developers feel they are producing new solutions to problems. Researchers feel they must be cautious. Developers will try most anything available if they think it will work. Researchers are concerned about conceptual issues and general principles. Developers want to design elegant solutions to specific problems. Researchers are scientists. Developers are craftspeople. Researchers find that developers go far beyond the data available and deal with situations that are far too complex to understand. Developers find that research is irrelevant to most of their daily problems. Researchers commit themselves to judgments only when they are extremely confident that they are correct. Developers, on the other hand, hope to be right at least some of the time, and never too wrong.[1]

It is small wonder, then, that researchers and developers are typically not the same people. It is also reasonable that as individuals, researchers and developers seldom interact directly even if they are dealing with the same problem. It is also understandable that the concerns of these two individuals, even when in the same domain, do not seem to directly overlap.

Yet the interaction between these two groups--either formally or informally--is critical for the progress of each group. Development efforts can benefit from the conceptual development of research efforts. Research can benefit from the direct experiences of development. The problem is that one cannot expect the interactions of these two groups to be natural.

[1]These are stereotypes of course, as many of the best developers display the characteristics of researchers in appropriate situations and vice versa. Yet these characteristics do describe a large number of situations.

What Development Has to Say to Research

Developers have two general classes of messages to deliver to researchers. The first class of messages are those that address involvement in development efforts that will enhance research work. The second class of messages consist of requests for research which would benefit the developer.

In the first class of communications are a number of messages. For one, there is a range of rich examples of cognitive phenomena that can be observed effectively in development situations. Equipment as well as naturalistic settings frequently exists for observations. Development efforts are then excellent situations in which researchers can develop intuitions about cognitive phenomena in complex settings and in which these phenomena can be systematically observed. Secondly, development efforts also offer an opportunity to manipulate presentations of the stimulus material through a range of media and content areas. Thirdly, the rules of thumb generated by developers provide worthy foci of attention in systematic research investigations. The "best guesses" of experienced developers provide insight into a range of information processing domains and beg for systematic investigation. Fourthly, direct participation in a development effort by a researcher provides this researcher with a perspective about the coordination of research and development which is unavailable in the typically isolated research setting. It provides the researcher with a sense of the kinds of research that would be valuable to development, should the researcher be interested in the application of his or her research efforts. It also provides the luxury of opportunities for extensive observation of situations which are not yet very well understood. Finally, particularly for the cognitive researcher, opportunities are afforded for observing thinking in interactive situations over a long period of time. Computer graphics and computer-controlled videodisks, as well as more standard computer text presentation systems, allow for the systematic observation of individual learning and problem solving in an interactive context.

The statements from developers concerning research that would be useful to them center around certain topics and the usefulness of different methods of presentation of research results. As an example of the first class of statements, the developer would benefit if more research investigations of cognitive phenomena were accomplished in naturalistic settings so that materials would be more directly relevant to development decisions. In addition, the developer would benefit from the description of theoretically motivated criteria which could be used in measuring the effectiveness of development efforts. Similarly, a language for the description and assessment of interactive situations would be useful to the developer to analyze these common classes of situations. In a slightly different vein, the developer would benefit greatly from an analysis of attitudes of the general public towards science, particularly as it has recently manifested itself in a great deal of interest in science presentations on television and reports of research results in newspapers and popular magazines. Such an analysis would hopefully provide the developer with insight into how to reach those individuals who do not identify themselves as being interested in science. In addition, and in a similar way, an analysis of the fascination of children and adults with current video arcade games, and the engagement of attention with these games, would be useful to the developer. Computer graphic presentations of mathematics and physics could surely benefit in their design with reference to these media.

With regard to the presentation of research results, developers would benefit from presentations that include examples of the phenomena studied, e.g., examples of a number of pictures used in a particular experiment or simulations of the experiments conducted. This would make it clearer to the developers which research results are applicable to their development efforts, and it would provide examples of specific materials which illustrate general principles which can then be tailored by the developers to their own domains. In addition, in the researchers' presentation of results, it would be useful to the developer to hear researchers' intuitions about where their results may or may not be applied.

Mathematic Imagery Projects: Some Attempts at the Application of Cognitive Principles

My mathematics projects--one funded by NSF-LOCI for the development of video modules for precalculus and the other funded by NSF-DISE for the development of a college mathematics computer graphics laboratory to emphasize the visual-spatial aspects of mathematics--provide specific examples of the kinds of opportunities available to the researcher in the development setting and the kinds of research required by development efforts.

In reading these brief specific suggestions, one should realize that I am not by training a developer, but instead a cognitive researcher. At some level these observations then are those of a researcher frustrated in development (1) because of a lack of time to follow up all research ideas, and (2) because of a lack of existing research applicable to development decisions. They are also the observations of a researcher who is enthusiastically doing development (1) because of a perceived personal responsibility for the application of basic research in socially beneficial domains such as education, (2) because mathematics is an excellent domain in which to formalize concepts related to pictorial communication, multiple representations, and spatial imagery, and (3) because of a general dissatisfaction with cognitive psychological paradigms which do not address pictorial communication in a sophisticated or interactive framework.

The Development of Video Modules for Precalculus (NSF-LOCI)

The LOCI projects, which I worked on with Ed Landesman, a mathematician, provided an excellent context for the investigation of different classes of explanations in the video format. As an example, in the early parts of the project we classified a number of methods of presentation, including the use of dialogue, the use of dynamic pictures, the explicit correspondence of algebraic and graphic displays, the use of real world examples and metaphors, and the inclusion of a student role model. Yet we used these techniques intuitively rather than systematically in the project, given that we needed to complete the modules rather than to develop a theory. An analysis of the differential effectiveness of these presentations in the explanation of mathematical concepts provides the researcher a rich domain for analysis and for the development of a theory of explanation.

Opportunities for analysis and comparison of lectures, video modules of lectures, and video modules using a range of video techniques exist in this project as well, because the mathematician and the topics developed in each of these different settings remained the same. Educational technologists would do well to examine these different media and the differential effectiveness of each in conveying mathematical concepts. Each medium does certain things well and other things not so well; this is acknowledged in the folklore of development and of education. A systematic analysis which included a common method of description for the different presentation formats and which described why certain techniques would be valuable for certain things would be theoretically as well as pragmatically interesting. Again, the LOCI development project had neither the time nor the resources to address these issues.

Another research opportunity offered by the LOCI project, one that would be more pragmatically useful to the developers than theoretically interesting to researchers, is an analysis of the perceptual aspects of the video media, including color, the angle of cameras in live action filming, and classes of edits between different formats. Such an analysis, especially if it had included specific examples and critiques, would have been invaluable to our development effort. Yet, short of developing this ourselves, we had no mechanism to acquire such an analysis.

Mathematics Imagery (NSF-DISE)

The DISE project now offers an extremely wide range of theoretically interesting research topics, many of which we are explicitly addressing during our first 2 years in preparation for our later intense development effort. One topic is the delineation of the relationship between spatial abilities and mathematical abilities. We are currently pursuing this in our attempts to develop a well-specified conceptual framework that includes explicit definitions of spatial abilities, the use of spatial representations in mathematical explanations, and mathematical abilities, as well as the interaction of these domains. There are obviously many topics in this domain that would be of interest to the pure researcher.

Another research focus is on the existing mathematics materials which use spatial representations. These have been generated intuitively as a means to explain complex ideas. Yet we don't know if they work, or why they work if they do. Developers will continue to generate such displays; researchers have the opportunity to assess these and to develop conceptual frameworks to guide future developments.

The presentation of spatial representations is a particularly rich research domain at present, given the multitudes of media that are becoming readily accessible to the developer. Videotapes and movies allow one to use moving displays, and, particularly in the case of videotapes, these can be individually tailored and viewed. Computer graphics and videodisks provide a wealth of visual imagery that can be presented in an interactive framework and that can include alternative scenarios to be chosen by students. As well as providing educators with a range of options, these media provide opportunities for research on dimensions of presentations which have not been possible with earlier technologies. And computer delivery systems can even be used to measure student performance and to monitor their problem solving!

In addition to providing a range of opportunities for theoretical work in research, the DISE project requires a number of things from the research community. For one, a method of measuring and describing subject interaction with moving pictorial displays is needed in order to assess the success and failure of particular development efforts. In addition, a language is needed for discussing pictures as methods of explanation rather than simply as referents to objects so that dimensions of explanations can be considered systematically. This language must include not only a consideration of features of single pictures, but also the sequencing of pictures, the interaction of pictures and text, moving pictures, and student interaction with and selection of particular pictures. The levels of descriptions provided by research communities are currently too constrained to be of much use to the developer who is engaging new technologies.

Conclusions

There is much more to say, as a developer and as a researcher, but I will stop here, for I think that I have begun a conversation between developers and researchers. And that is my intent.

I have listed general development issues for researchers to consider, and I have provided specific examples from my own work to illustrate these. From my own perspective, that of a researcher only recently immersed in development, I have suggested that it is to the researcher's best self-interest to work in a development setting, in order to develop intuitions, to take advantage of naturalistic settings, to use available technologies, and to study the rules of thumb developed by practitioners. I have also suggested that, to be responsible to development, researchers should develop theoretical frameworks addressing more complex situations, considering explanation as well as understanding in investigations of information processing, and setting forth a language to describe subject interaction with new technologies, as well as a language to describe pictorial communication.

In closing, I would like to encourage researchers to do development and developers to do research. As a researcher in development, one can view complex phenomena that would normally escape attention, and one can be directly responsible for the follow-up of one's own research in an applied setting. As a developer in research, one can enjoy the luxury of developing theoretical frameworks and following up intuitions that have been neglected due to the production pressures in development settings. I suggest this because I think the individuals involved would benefit, and because I see this as the most productive mechanism for the interaction of research and development. Without that interaction at an individual level, I see little opportunity for effective interaction of the two domains, and I consider such interaction necessary for both research and development.

EDUCATION IN SCIENCE AND TECHNOLOGY FOR ALL AMERICANS

Izaak Wirszup
The University of Chicago
Department of Mathematics
5734 University Avenue
Chicago, Illinois 60637

Dr. Izaak Wirszup, Professor of Mathematics at the University of Chicago and the Director of a Development in Science Education project entitled "Survey of Recent East European Literature in School and College Mathematics," caused nation-wide comment in 1980 when he wrote the National Science Foundation comparing Soviet and American mathematics and science education programs, and detailing his concerns about the teaching and learning of these subjects in U.S. schools. As a result of his letter, the President of the United States ordered the Secretary of Education and the Director of the National Science Foundation to conduct a thorough investigation of the issues raised by Dr. Wirszup and jointly to report their findings. This study resulted in the issuing of "Science and Engineering Education for the 1980s and Beyond." Wide editorial comment in the nation's newspapers has been attracted to the problem and Dr. Wirszup has been invited to testify before several committees of the U.S. Congress. Dr. Wirszup was born in Wilno, Poland. He received his Ph.D. in Mathematics from the University of Chicago, and has served as Professor of Mathematics there since 1965. Dr. Wirszup has a long and distinguished history of serving as consultant on advanced mathematics programs to Yale and Stanford Universities, to the Ford Foundation and the Encyclopedia Britannica, and to the U.S. Commission for Mathematics Instruction.

In December 1979 I sent the National Science Foundation (NSF) a report on my comparative study of Soviet and American pre-university education. The report pointed out for the first time the Soviet challenge in science, technology, and engineering programs, which had been launched as early as the 23rd Communist Party Congress in 1966. It described the Soviets' ongoing "educational mobilization"--the innovative restructuring of their secondary educational system to include vast manpower training programs, their radical curricular reforms, and, above all, their tremendous investment in human resources.

The response to my report was immediate and much greater than expected. On February 8, 1980, President Carter ordered the Director of the National Science Foundation and the Secretary of the Department of Education to review our science and engineering educational policies; the result was the publication last fall of a report entitled "Science and Engineering Education for the 1980s and Beyond." The findings of both reports have been discussed in professional journals and in the daily press here and abroad. NSF noted that my research had been a factor in the President's order, and the NSF-Department of Education study itself states that my conclusions were corroborated by a study by SRI International and by the work of independent experts.

Before proceeding, let us remind ourselves of the fundamental difference between the educational philosophies of our country and of the Soviet Union. As an expression of the American ideal of democracy, our goal in education is the individual development of the human being, with the freedom to choose his life's work. From the point of view of civic education--fostering an appreciation of freedom and democracy--our schools are among the finest in the world. The Soviet principle, on the other hand, is that education is designed to serve the state. Their highly centralized educational system is organized to further the Communist Party's aims, to raise the technological and industrial level of the Soviet Union, and to increase its military power and political influence.

By expert opinion, the United States today is ranked the world's leader in science and technology, although this position has been eroding over the last decade. Our major universities and their graduate programs are the best in world, but the research and training leadership they represent is based on a relatively small, if superb, elite. In contrast, Soviet science and engineering training programs are of such magnitude, and their drive for supremacy so determined, as to pose an enormous challenge to this American preeminence.

In spite of their tremendous achievements, however, I do not advise imitation or adaptation of Soviet educational goals, procedures, or practices.

I shall focus here on a few striking examples from American and Soviet education in mathematics, the sciences, and other disciplines, and then touch briefly on some of the pervasive problems in American education, relating them to the current state of our productivity and defense preparedness. Finally, I shall make some recommendations for radically improving our school system, especially in science and technology, and discuss the urgent need for establishing and supporting national educational leadership in the United States.

* * *

The U.S.S.R.'s educational system is the product of planning, experimentation, and investment spanning more than half a century.

For many years the Soviets were content with the creation of a small scientific elite, while the majority of their students remained at low levels of academic performance. Many factors converged to change this educational policy. A labor shortage in the European portions of the U.S.S.R. threatened the continued supply of trained manpower. The introduction of high technology to the Soviet military-industrial complex demanded workers and soldiers with a better understanding of scientific and technological principles. Meanwhile, their own studies showed increased productivity from workers who had received a general education plus technical training in schools rather than on the job, and research in the academies led to notable advances in educational psychology, paving the way for more ambitious curricula and effective teaching methods at every school level.

It is indicative of the depth of the Soviets' commitment to a strong educational system (and a main factor in its success) that their top research talent has devoted so much to the improvement of the country's schools. For example, A.N. Kolmogorov, one of the great mathematicians of the century, has for the past 15 years directed the entire school mathematics reform. Not only has he played a decisive role in determining the content of mathematics curricula, but he has also been in the forefront of Soviet research in educational psychology and mathematics instruction. In addition, Kolmogorov is a co-author and editor-in-chief of the three textbooks Geometry (grades 6-8) and the two textbooks Algebra and the Elements of Calculus (grades 9-10). Similarly, Academician I.K. Kikoin, the world-renowned physicist, has been a leader in the Soviet school physics reform.

The famous mathematician I.M. Gel'fand has been working with gifted secondary school students for the past 45 years. The programs for discovery and training of mathematically talented youngsters are an exceptional Soviet educational achievement, and the literature created for the programs has no equal in excellence or scope.

The U.S.S.R. Academy of Sciences sets educational policy and directs curriculum development. More directly responsible for curriculum reform, revision, and implementation is the U.S.S.R. Academy of Pedagogical Sciences, the chief Soviet educational research center. No other institution remotely approaches this Academy and its various institutes in size, range of operation, and quality of research. Five hundred senior research psychologists are associated full time with its Institute of Educational Psychology, representing the unique school of L.S. Vygotskii and A.R. Luriya. The extraordinary Soviet research in the psychology and methods of learning and teaching mathematics has been applied in the new curriculum.

The school reforms of 1966 have been forcefully and rapidly implemented. Serious obstacles have been encountered, especially with the new 2-year calculus requirement, but carefully monitored experimentation and change have steadily improved programs. The general restructuring and curriculum reforms preserve the goal of a diversified multitrack system of education that (1) keeps every student in school through the secondary level; (2) guides him into a course of study corresponding to his abilities; and (3) ensures a large pool of trained, well-educated labor for Soviet industrial production. The Soviets have been very successful in meeting these objectives. No less than 5 million students, or 98 percent, now complete a secondary education annually. Especially impressive is the fact that over 3 million skilled workers and white-collar technicians are produced each year by the secondary school alternatives. These technical-vocational and specialized professional schools frequently offer programs in science and engineering that correspond to between 2 and 3 years at U.S. technical institutes or colleges.

In only 10 years, the Soviet compulsory program for all students covers the equivalent of at least 13 years of American schooling in arithmetic, algebra, and calculus, and does so much more thoroughly and effectively. The American 1-year geometry course offers but a very small fraction of the Soviet 10-year geometry curriculum.

* * *

Let us review U.S. secondary education in light of the recent Soviet achievements.

Of the approximately 4 million American youngsters who reach the age of 17 each year, 3 million have had arithmetic for 9 years. In the first 6-8 years their teachers generally have no special training in mathematics. Nine years of repetitious drill is a waste and a terribly damaging experience. The resulting feelings of near-stagnation and incompetence are both a cause and a symptom of the deplorable state of U.S. mathematics and science education, and consequently of our technical training.

In other industrialized countries, children complete arithmetic in 6 years. The Russians, however, cover arithmetic proper in the first three grades and complete arithmetic and even start algebra in grades 4 and 5. What has helped to make this remarkable achievement possible is that from the fourth grade on, mathematics is taught by a specialized mathematics teacher, whose mathematical training is equivalent to at least a master's degree program in the United States. Even Soviet teachers for grades 1-3 receive extensive training in mathematics, the sciences, and educational psychology and teaching methodology based on advanced research.

Comparisons in geometry are even more disturbing. Only half of our population takes 1 year of plane geometry. Yet most of these students simply never learn geometry, because we attempt to teach it in a single year, while empirical evidence and modern educational psychology tell us emphatically that we cannot.

In 1959 a French periodical printed a paper by Pieter van Hiele entitled "La pens;ee de l'enfant et la g;eom;etrie," one of the most important breakthroughs in the psychology of learning and teaching geometry. Pieter and Dina van Hiele-Geldof, together with their professor, the famous Dutch mathematician and educator Hans Freudenthal, introduced the concept of five levels of mental development in geometry. The paper went virtually unnoticed in both Western Europe and the United States. I was, however, fortunate to learn from Russian monographs of the van Hiele paper and of significant research and experimentation done by the Soviets on the van Hiele-Freudenthal theory. The Russians had not only verified and refined the van Hieles' work, but had subsequently adopted this theory as a foundation of their new geometry curriculum and their innovations in the methodology of teaching geometry.

Since American students who take the 1-year high school course generally have no prior knowledge of geometry and are at the first psychological level of development, they cannot be expected to master material from the fourth development level, and, in fact, our students never do learn it. Furthermore, our high school students are not being taught solid geometry. Therefore, they rarely have a workable perception of three-dimensional space, which is essential for studying science, technical design, and engineering.

In contrast, all Soviet students study geometry for 10 years: 5 years of intuitive geometry, 3 of semirigorous plane geometry, and 2 of solid geometry.

There are 303,000 specialized mathematics teachers in the Soviet system of general-education schools. Each year the pedagogical institutes train some 22,000 new mathematics teachers. An outstanding journal for mathematics teachers, Matematika v shkole (Mathematics in the School) is published bimonthly in issues of nearly 400,000 copies of 80 pages each. Its American counterparts, The Mathematics Teacher and The Arithmetic Teacher, have a total circulation of 84,000.

American secondary school physics, another building block of science education and technical training, is in disastrous condition and must be changed radically. Less than a tenth of our high school students take a 1-year physics course. The total number of physics teachers--for over 17,000 U.S. school districts--is only 10,000 and shrinking rapidly. In the Chicago public school system there is only one physics teacher for every two high schools.

In the U.S.S.R. secondary school students take 5 years of compulsory physics courses. In its 200 pedagogical institutes the Soviet Union trains 8,500 specialized physics teachers each year. The total number of physics teachers in Soviet general education day schools is 123,000. The Soviet journal Fizika v shkole (Physics in the School), a 94-page bimonthly, is published in 484,000 copies, as opposed to the 7,000 copies of its American counterpart, The Physics Teacher.

The pattern continues in other subjects. In chemistry, only 16.1 percent of our high school students take a 1-year course, while all Soviet youngsters complete 4 years of chemistry, including a full year of organic chemistry. Soviet students also receive 5½ years of compulsory training in biology (compared to the 1-year biology course in the United States), 1 year of astronomy, 3 years of mechanical drawing, and 10 years of workshop and technical training.

The Russian comprehensive journal for chemistry teachers, Khimiya v shkole (Chemistry in the School), is published in 157,000 copies. For biology teachers, Biologiya v shkole (Biology in the School) is published in 154,000 copies.

The disparity between the level of training in science and mathematics of an average Soviet skilled worker or military recruit and that of an average American high school graduate, industrial worker, or army recruit is so great that comparisons are almost meaningless.

Our educational crisis is by no means limited to mathematics and the sciences. Barely 9 percent of our students have any exposure to geography as a separate subject, mostly in the form of one-semester courses. Geography teaching has all but disappeared; fewer than 1,700 secondary school teachers are members of two professional geography associations. It is hardly surprising that Army studies of our recruits reveal "a markedly lower ability to read maps and recognize enemy targets." The Soviet Union, on the other hand, trains over 6,000 specialized secondary school geography teachers each year to conduct a 5-year sequence of compulsory courses in physical, economic, and political geography. The total number of geography teachers in Soviet general education day schools is 98,000.

Similarly, all Soviet children are obliged to take 6 years of a foreign language, while fewer than 18 percent of U.S. public high school students study any foreign language, and fewer than 4 percent take more than 2 years.

We have seen that the Soviet curricula are reinforced by an extensive system of teacher training and teacher support publications. Students also enjoy such support systems, in the form of various extracurricular mathematics and science activities and publications integrated with the school curriculum. Hundreds of thousands of youngsters participate in mathematics clubs, physics clubs, and various technical clubs--organized either in their schools or at universities, pedagogical institutes, and technical institutes or pioneer houses. The vast literature created for these extracurricular programs has no equal anywhere in the world. The series Popular Lectures in Mathematics, with over 50 volumes, has been published in several editions and in millions of copies, and translated into dozens of languages.

To help develop a strong interest in science and technology, Soviet authorities publish several popular journals for both young people and the general public. All of these journals are of high quality and enjoy a broad readership. Examples are Nauka i zhizn' (Science and Life)--164 pages, 3 million copies per month; Tekhnika molodezhi (Technology for Youth)--68 pages, 1,700,000 copies per month; Yunyi tekhnik (Young Technician)--84 pages, 1,880,000 copies per month; and Znanie-sila (Knowledge is Strength)--52 pages, 500,000 copies per month.

A major vehicle for fostering and stimulating secondary school students' interest in mathematics and physics is a highly original periodical for the young called Kvant (Quantum). Since 1970 the U.S.S.R. Academy of Sciences and the U.S.S.R. Academy of Pedagogical Sciences have jointly published this monthly journal for secondary school students interested in physics and mathematics. Its editor-in-chief is Academician I.K. Kikoin, and the first deputy editor-in-chief is Academician A.N. Kolmogorov. The editorial board includes such famous scientists as V.G. Boltyanskii and P.L. Kapitsa (Nobel laureate in physics). Each issue of 68 pages is in an edition of 234,000 copies. The American counterpart, The Mathematics Student, is issued six times a year, in a run of 34,000 copies, and is all of six pages long. Because of lack of funds, publication of The Mathematics Student is being discontinued.

Soviet educational requirements sound excessive to Americans in particular. Our 75 percent high school graduation rate compares unfavorably not only with the U.S.S.R.'s 98 percent, but with Japan's 90 percent. The vast majority of our high school students have not studied physics, chemistry, geography, or a foreign language, and have had only a modicum of mathematics. We are virtually alone among the industrialized nations in expecting such minimal accomplishment of our students and our schools, and we are already paying the price.

A recent statement by Peter J. Denning, president of the Association for Computing Machinery, warns, "We, the United States, are losing our lead as world economic leader because our productivity is in decline. Even our strongest area, computers, is now seriously challenged by Japan and Germany. We face severe personnel shortages that threaten our abilities to conduct basic research, to train new scientists, and to educate young people properly in science. As we enter a decade dominated by technology, our primary and secondary school systems continue to turn out young people who are scientifically illiterate, and who will eventually be making decisions governing a technological society. We are in a productivity crisis and the current education system is geared to perpetuating it."

The weaknesses of the American educational system have become a national malady that gnaws at our economic strength, our competitive edge in technology and production, and our ability to defend ourselves. We can take pride in the achievements of a small but superb corps of top-level scientists. But the distressing fact is that the overwhelming majority of our population lives in a state of debilitating scientific illiteracy.

Many undereducated young people are turning to the U.S. Armed Forces as an employer of last resort. There is little need to cite already published data concerning the results of qualification tests and the state of preparedness of our national defense. Suffice it to say that, at a time when advanced and sophisticated science and technology are becoming the keys to our national survival, military training manuals formerly written at an 11th grade level are now being written at 6th grade level.

A dangerous gap exists between our educational standards and those of other nations, especially the Soviet Union. We must begin to view education as a critical renewable resource essential not only to our well-being, but to our survival.

It is not generally known that the U.S.S.R.'s expanded exercise of power is based not just on its enormous arms buildup of the past 15 years, but on concurrently developed science education and manpower training programs that have created a military machine manned by highly skilled and educated personnel. The Soviet Union's tremendous investment in human resources, unprecedented achievements in the education of the general population, and immense manpower pool in science and technology are having an immeasurable impact on that country's scientific, industrial, and military strength. It is my considered opinion that the Soviet educational mobilization, although not as spectacular as the launching of the first Sputnik, poses a formidable challenge to the national security of the United States, one that is far more threatening than any in the past and one that will be much more difficult to meet.

Our schools are not preparing the great majority of our youth for a productive and independent life in an age dominated by science and technology. There is increasing evidence that our present primary and secondary educational system is totally inadequate for the Nation and its needs.

We have claimed that ours is the most democratic school system. Yet it produces, in the top few percent, only a tiny minority whose education even approaches the needs of the age of science and technology. How, in addition, can we call high school graduates who have never studied geography, have no foreign language, physics, chemistry, or geometry, and only the rudiments of arithmetic and algebra, educated? If through this system we have become a two-culture society, a small scientific elite and a mass of near-illiterates, then our educational system is not, in fact, democratic.

One of the major defects in our educational system is that the United States has not matched the range and availability of the manpower training programs the Soviets have devised. Secondary vocational and technical education in this country lacks both prestige and appeal and has long been the poor relation of more strictly academic studies. It is reserved, where it is available at all, for students who are no longer expected to compete academically, and its contribution to our manpower resources is negligible.

Millions of our young people are being shortchanged, thrown out on the job market with no skills and little chance of finding a job, and there is no alternative institution to give them the training they need.

Only the talented, the ambitious, or those lucky enough to attend schools that can support better programs and teachers can take advantage of their full benefits. The average student in the average school and the disadvantaged student suffer from diminished standards of achievement, a narrowing selection of educational alternatives, an almost complete lack of professional orientation, and an absence of support for remedial and continuing education once they leave the school system.

The programs we have for our gifted students are painfully insufficient. Ideally, these are our future leaders in every field, but we do not equip them for such responsibility. This is a great waste of one of our most valuable resources.

The Soviets see no contradiction or inconsistency in their social theories in a school system that offers maximum education to everyone while striving to train those who are most able for elite positions in science, technology, and the military.

Let me reiterate that in spite of their tremendous achievements in education and manpower training, I am not advocating imitation or adaptation of the Soviet system in the United States. Still, there are important lessons to be learned from the Soviet reforms. At the center of these stands the fact that, political and ideological issues aside, the Soviet educational system is now designed to maximize the utility of every student.

The NSF-Department of Education report to the President emphasizes that the guiding principle of our educational system for the 1980s and beyond should be a "new national commitment to excellence in science and technology education for all Americans." To achieve this, our present system must undergo radical changes of a comprehensive, organizational nature, as well as more specific curricular reforms.

I would like to recommend the following general organizational changes:

1. Allow only specialized teachers to teach mathematics and science courses from grade 5 on.

2. Institute new secondary school programs (and reorganize most of the existing technical and vocational schools) to provide an alternative avenue within our school system to train white-collar technicians (e.g., computer programmers), middle-level professionals (e.g., junior managers, industrial foremen), and skilled workers (e.g., auto mechanics and workers employing computer-programmed equipment and other high-technology processes).

The success of these programs will depend on cooperation between all segments of our educational system--such as high schools, junior colleges, institutes of technology, colleges, business schools--and industry, commerce, and labor organizations.

3. Establish continuing improvement and retraining programs for primary school teachers, especially those who teach arithmetic in grades 1-4. Inservice and preservice programs should be devoted primarily to teaching content, particularly the fundamental concepts of mathematics and science.

4. The present shortage of mathematics, engineering, and science teachers, together with the proposed revisions in teacher qualification requirements for the primary schools, will necessitate a comprehensive organizational change in regular teacher training and improvement programs. Our higher educational institutions must examine their past and present records of performance in teacher training and commit themselves to unshakable standards of excellence and professionalism.

5. Institute a program for the development of a literature on teaching methodology for all subjects at all levels of the primary and secondary school system. This literature should address content of instruction and teaching methods. It should make use of the classroom experience of outstanding teachers, modern research in the psychology of learning and teaching, and the theory and use of instructional materials, including audiovisual teaching aids, hand calculators, and minicomputers. A thorough, comprehensive literature of this kind, developed over a long period of time and continually revised and improved, is being used in all communist countries to assist inservice and preservice teachers. Such a literature is completely lacking in the United States.

6. Organize extracurricular programs to develop an interest in mathematics, science, and technology in all students. These programs should be carefully planned to excite students and insure the participation of the best teachers and prominent scholars from all school levels, as well as scientists from industry. These programs should be preceded and accompanied by a specially prepared literature that makes use of all the available media--books, carefully designed and widely distributed periodicals, and video presentations on tape and disc. The Public Broadcasting System, museums, and other public educational institutions should be encouraged to provide integrated programs and services.

7. Organize new programs, and expand existing ones (such as summer programs) for the discovery and training of talented children from the earliest possible age.

8. Greatly expand the system of preschool education. Appropriate teacher training programs should be introduced for this level. Children from the age of 3 or 4 should become acquainted in an organized way with the concept of number, basic geometric notions, and underlying patterns and relationships in mathematics and science.

We can gain some useful insights here from a study of the Soviet preschool system, which involves 13.5 million children. Soviet research in the psychology of preschool learning and teaching provides a rich resource we have largely ignored.

9. Organize or expand continuing education programs for our adults who need additional training. We must enable individuals to understand and appreciate new developments in science and technology, and offer them an opportunity to study in depth. Schools from secondary level on up should be used, as well as museums and the popular media.

10. Organize mass professional orientation programs for all age groups. Again, the resources of all institutional segments of the society should be exploited.

The following curricular changes are indispensable and urgently recommended:

1. Develop a completely new program for all children covering all arithmetic in the first 6 years of school. Intuitive geometry should be an integral part of the new program from the first grade on. Introduce algebraic thinking in the last 2 years of this 6-year program.

2. Offer all students in grades 7-9 a new 3-year sequence in algebra and a separate, parallel, 3-year sequence in semirigorous geometry.

3. Follow the example of other modern nations and teach the sciences in multiyear sequences.

From the van Hiele-Freudenthal research on development levels in geometry it is evident that mastering an axiomatic and rigorous geometry course in 1 year is generally impossible. Likewise, the existing 1-year courses in biology, physics, chemistry, and geography are inadequate and should be replaced by at least 2-year but preferably 3-year sequences consisting of a descriptive introductory course followed by 1 or 2 years of rigorous and quantified courses.

4. Introduce a completely new sequence of courses called Technology and Engineering, to begin in grade 7 and to be offered to all students in all school systems. The curriculum should combine, whenever possible, both theoretical and practical studies, ideally using modern and well-equipped shops at selected nearby industrial or commercial enterprises.

5. Raise the minimum requirements for graduation from high school to include 3 years of mathematics and 2 years of science.

6. Make optimal use of calculators and microcomputers in the new mathematics program. The abundance of these tools in the United States should be exploited to greatest advantage at all educational levels, starting in the primary schools.

7. In high school, offer separate courses in computer science, probability and statistics, and solid geometry, in addition to the existing courses in advanced algebra and calculus.

8. Accompany these comprehensive organizational and curricular reforms with research and development programs giving special attention to integration of the sciences, particularly in their relation to mathematics. This research should be applied to the interrelationships of subjects and the establishment of a logical order of presentation in the school curricula at each level.

9.* There is one important lesson we can learn from the experience of the post-Sputnik curricular reforms of the late 1950s and early 1960s. The goals of these reforms were essentially different from the goal our present educational crisis demands, i.e., "a new national commitment to excellence in education, especially in science and technology, for all Americans." Our current goals need to be truly democratic in the fullest sense.

Past projects were conceived with the purpose of preparing new text materials and introducing them in the schools. They were essentially one-shot programs of 4-5 years' duration. Examples are the SMSG (School Mathematics Study Group), PSSC Physics, and the BSCS Biology Project. They did produce some very good text materials, but the initiating projects soon expired, and the new materials developed were left without continuing programs of correction, revision, improvement, or review.

Such curricular reforms are conducted in a completely different way in Western Europe and in the Communist countries. In these countries curricular reform begins with intensive planning, both comprehensive and specific, with strong participation from top scientists,

*The main idea of item 9 was suggested by Professor Benjamin S. Bloom of the University of Chicago.

educators, and experts. Text materials are then produced, but they are not left for random implementation. Special permanent institutions, existing or created for the purpose, are assigned the responsibility for continuous supervision, implementation, review, and revision of new texts and curricula. Some of them are also engaged in the process of training and retraining teachers.

Our past mistakes should not be repeated. We must create a permanent national curriculum center and a national review board in science and technology. These should consist of the Nation's top scientists and technical experts who have an understanding of education, of scholars, outstanding teachers, psychologists, and educators, who would supervise the development of new curricula materials. They would also oversee the correction and improvement of both curricula and teaching and learning, and would direct regional R&D centers. The national center would periodically report on national progress.

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In contrast to the tremendous contributions of Soviet scientists and scholars to their nation's education, our own scientific community, with a handful of notable exceptions, has demonstrated no commitment to American pre-college science and mathematics education in the past 15 years. This negligent attitude toward education and school teachers has also contributed to our society's indifference to primary and secondary schooling. This situation cannot and must not continue. For the sake of the scientific community's own survival, and for that of the Nation, our top scientific research institutions, including the National Academy of Sciences and professional associations of research scientists, should help to reshape American secondary education. Their most dedicated representatives, once engaged in the problems of learning, should join with educators and teachers in striving toward a common national goal.

* * *

The Nation desperately needs an educational revitalization. We must admit the necessity of immediate action to renew American schooling as a whole.

The NSF Directorate for Science and Engineering Education can and should have a major role in this effort. It was responsible for the post-Sputnik curricular reforms in mathematics and the sciences that helped to produce a new generation of scientists--the youngest members of our current elite.

Today the Directorate is the leading agency in the design, development, and implementation of science, mathematics, and engineering education. The Directorate has become a focal point for innovation. It attracts proposals from the most dedicated educators, works closely with professional associations, and conducts intensive discussions on structural change and curricular reform in our school system.

In the past few months I have addressed many groups--industrial leaders, educators, scientists--and I have urged them to take an active role in our educational revival. As they approach these problems, many for the first time, they seek the experience and advice of experts. The NSF Directorate should now be encouraged to develop even further, to coordinate and lead the interaction between an educational system in need of sweeping change and the industrial and social beneficiaries of that change.

The economic revitalization of our society and the insurance of a strong defense unequivocally demand a national program to fully develop our human resources, beginning with the reform of our elementary and secondary educational system. If we fail to make this investment, the consequences will be disastrous.

It is a fallacy to suppose that market forces can efficiently and quickly meet our educational needs. It takes 20 years to produce a qualified scientist or engineer, of which the first 10-12 years of training are crucial. If our public schools cannot attract and hold students to the sciences, a generation of future scientists will be lost forever. Yet, as virtually every standard measure of academic performance now shows, our educational system is producing fewer and fewer able students in all fields.

These are challenges that our infatuation with sophisticated management techniques cannot help us meet. Leaders of American industry must recognize, as their foreign competitors already do, that there is no substitute for technological experience and innovation. We must acknowledge that an educated population and a well-trained manpower force are essential to the recovery of our economic leadership and national defense.

This will require, above all, creativity, energy, and wisdom. Our goal should not be to imitate Soviet achievements, methods, or systems, but to conceive whatever new forms of American education are necessary to preserve our freedom.

Fortunately, the general public is showing increased awareness of the close and intricate relation between the state of our educational system and our economic position and national security. Representatives of every segment of society, from leaders of industry to concerned parents, are looking for moral leadership and a nationwide program to solve the present educational crisis. Even more than funding, society needs guidance, purpose, and hope. It will then be ready to make serious commitments to an educational revival.

Our past leaders failed to plan and support the development of new energy sources to make the Nation energy self-sufficient. Today we are living with the real and impending hardships resulting from that lack of preparation. Can we afford to make the same mistake with our invaluable human resources? Our present educational crisis calls for strong leadership, with foresight and patience, but also the ability to act decisively. To give up, to procrastinate, or to plan only for the short term would be to mortgage our freedom and our future.

THE SCIENCE/MATH RESEARCH AND DEVELOPMENT WORKERS: HOW THEY CLUSTER, WHAT LINKAGES CONNECT THEM, WHAT BARRIERS SEPARATE THEM

Joseph I. Lipson
National Science Foundation

Dr. Joseph I. Lipson speaks authoritatively about the interaction of development and research, having just completed three years as Director of the Division of Science Education Development and Research. Always keen about increasing the cooperation between development and research, Dr. Lipson makes many insightful observations in his speech based on his experiences during his term. Dr. Lipson received a BS degree in Physics from Yale University, and a Ph.D. in Physics from the University of California at Berkeley. As Director of Projects, WICAT, Inc., a non-profit educational institute in Utah, Dr. Lipson headed the development of the first instructional videodisc and an advanced computer assisted instruction system for the Federal Judicial Center. He has returned to his position at WICAT. Dr. Lipson has a long record of working for support of the improvement of education in the sciences, and has written and spoken extensively on that subject. He has held teaching and administrative posts at the University of Mid-America, the University of Illinois at Chicago Circle, Nova University, the University of Pittsburgh and the University of Alberta.

I believe that within the next 10 years we will have an applied science of education. This means that we will have a comprehensive set of principles of teaching and learning. These principles or relationships will be sufficiently broad and specific to permit us to design effective and appealing learning environments. Almost certainly these learning environments will make extensive use of computers and related devices. The design will probably include an altered organizational structure, attention to the social aspect of learning, and a high degree of individualization. I would predict that cognitive science will play an integrative role in spanning the range from neuroscience to educational research.

The history of molecular biology as well as of other subjects convinces me of the importance of closely connected communities of scholars who share common goals of what they are trying to understand. Typically, fruitful communities include individuals who are highly theoretical as well as those whose interests are applied and practical. Can those of us who are interested in practical development in science education join with those who try to understand how and why individuals learn science in order to accomplish the transformation I anticipate?

Characteristics of the Science Education Research Community

Characteristics of RISE Principal Investigators

Table I lists the characteristics of the Research in Science Education (RISE) principal investigators for Fiscal Year 1980 according to (a) the doctoral degree of the principal investigator (PI), (b) the type of institution receiving the award, (c) the professional affiliations of the PI, and (d) the professional publications of the PI. These data were drawn from the proposal files and organized by Dr. Kathleen O'Keefe and Dr. Rita Peterson, RISE Program Director. The following is their summary;

> The largest percentage of those receiving grants had doctoral degrees in the field of education or science education (SE); but nearly as many held Ph.D.'s in mathematical and physical sciences (MPS) or biological, behavioral and social sciences (BBS). Most awardees had bachelor's degrees in mathematical or physical sciences.
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> Most applicants were affiliated with public institutions. Surprisingly, however, one of every four applicants was from a not-for-profit organization. More than twice as many awards went to principal investigators in institutions classed as research universities as went to PIs in other doctoral-granting universities, comprehensive colleges and universities, and liberal arts colleges combined.
>
> Applicants had memberships in a wide range of professional organizations, with the American Educational Research Association (AERA) and the American Association for the Advancement of Science (AAAS) heading the list. While successful proposers cited membership in the National Association for Research in Science Teaching much more frequently than nonsuccessful proposers (22 percent vs. 3 percent), successful proposers were much more likely to belong to the AERA than to NARST (68 percent vs. 22 percent). Those receiving grants played more prominent roles in professional organizations, serving as officers or as members of review or editorial boards for journals published by the organizations (61 percent vs. 39 percent for the nonsuccessful applicant group). Those who received awards were more frequently authors of books than those denied grants (73 percent vs. 45 percent).

One characteristic of the investigators that does not show in the table is the distribution of principal investigators in fields outside of the social and behavioral sciences. People who consider their field to be physics and/or math are much more likely to be interested in research in science education than are people in fields such as chemistry, biology, geology, or engineering.

Table I(a)

RISE INVESTIGATORS FY 1980

DOCTORAL DEGREE OF PI	AWARDS NO.	AWARDS PCT.	DECLINES NO.	DECLINES PCT.
Mathematical and Physical Sciences	6	15%	5	15%
Biological, Behavioral and Social Sciences	7	17%	12	36%
Education and Science Education	18	44%	4	12%
Engineering and Applied Science	0	0%	1	3%
Liberal Arts	3	7%	2	6%
No Doctoral Degree	0	0%	2	6%
No Information Available	7	17%	7	21%
	41	100%	33	99%

Table I(b)

RISE INVESTIGATORS FY 1980

TYPE OF INSTITUTION	AWARDS NO.	AWARDS PCT.	DECLINES NO.	DECLINES PCT.
Research Universities	21	51%	12	36%
Doctorate Granting Universities	4	10%	6	18%
Comprehensive Colleges and Universities	5	12%	4	12%
Liberal Arts Colleges	0	0%	2	6%
School Districts	1	2%	1	3%
Nonprofit Organizations	10	24%	8	24%
	41	100%	33	99%

Table I(c)

RISE INVESTIGATORS FY 1980

PROFESSIONAL AFFILIATIONS OF PI		AWARDS NO.	AWARDS PCT.	DECLINES NO.	DECLINES PCT.
AAAS	Amer. Ass'n Adv. Science	19	46%	9	27%
AERA	Amer. Ed. Research Ass'n	26	63%	16	48%
AETS	Ass'n Ed. Teachers of Science	6	15%	2	6%
APA	Amer. Psych. Ass'n	8	20%	8	24%
NARST	Nat'l Ass'n for Research in Science Teaching	9	22%	1	3%
NSTA	Nat'l Science Teachers Ass'n	9	22%	1	3%
NCTM	Nat'l Council Teachers of Math	7	17%	3	9%
PDK	Phi Delta Kappa	7	17%	3	9%

Table I(d)

RISE INVESTIGATORS FY 1980

PROFESSIONAL PUBLICATIONS OF PI	AWARDS NO.	AWARDS PCT.	DECLINES NO.	DECLINES PCT.
Books	30	73%	15	45%
Chapters in Books	18	44%	16	48%
Articles in Research Journals	33	80%	29	88%
Articles in Applied or Non-Research Journals	21	51%	13	39%
No Publications	1	2%	2	6%
No Information Available	1	2%	1	3%

Characteristics of DISE Principal Investigators

Table II displays the characteristics of the Development in Science Education (DISE) investigators for Fiscal Year 1980 according to (a) their doctoral degree, (b) their institution, (c) their professional affiliations, and (d) their publications. These data were gathered by Dr. O'Keefe.

Out of 59 awards made in FY 1980, only 19 percent went to investigators with doctoral degrees in education or science education, as contrasted with 44 percent who received their doctoral degrees in math, physical science, biology, behavioral science, social science, engineering, or applied science.

Research universities dominate the awards with 32 percent of the 59 awards. Not-for-profit firms were a close second with 27 percent of the awards. Although 2-year colleges educate a large fraction of undergraduate science students, only one award was made to a 2-year college, and this is a matter of some concern to us.

Generally, developers listed fewer professional organizations. Fourteen percent belong to the AERA and 10 percent belong to each of the following organizations: AAAS, Mathematical Association of America (MAA), and National Council of Teachers of Mathematics (NCTM). Few of the investigators listed membership in NARST or National Science Teachers Association (NSTA).

Interestingly, few DISE PIs listed instructional materials (e.g., texts or films) among their publications. However, a sizable 34 percent of those getting awards listed executive/editorial responsibilities with national organizations, and 42 percent had written books.

Similarities and Differences between RISE and DISE PIs

For those PIs for which information is available for FY 1980, there are some differences between RISE and DISE PIs. RISE investigators are much more likely to have a background that specifically prepares them to conduct research in science education (e.g., a Ph.D. in psychology or science education) while DISE investigators are more likely to have a degree in one of the sciences.

DISE awards were less likely to go to the research universities, although both award lists have a surprisingly large representation of not-for-profit firms. RISE investigators belong to many more professional associations than do DISE investigators.

Both groups have similar publication records, with the nod in listed publications representation going to the RISE investigators. A husky 70 percent of the DISE investigators, however, list research journal articles among their publications.

Table II(a)

DISE INVESTIGATORS FY 1980

DOCTORAL DEGREE OF PI	AWARDS NO	DECLINES NO.
Mathematical and Physical Science	14	7
Biological, Behavioral and Social Sciences	10	5
Education and Science Education	11	18
Engineering and Applied Science	2	1
General Science	2	1
Liberal Arts	1	0
No Doctoral Degree	8	10
No Information	12	7
	59	49

Table II(b)

DISE INSTITUTIONS - FY 1980

TYPE	AWARDS NO.	DECLINES NO.
Research Universities	19	16
Doctorate Granting	8	10
Comprehensive Colleges and Universities	8	9
Liberal Arts	4	0
Two Year	1	2
Engineering and Technology	1	2
School Districts	0	1
Not-for-Profit	16	9
For Profit	2	0
	59	49

Table II(c)

AFFILIATIONS OF DISE PIs - FY 1980

		AWARDS NO.	DECLINES NO.
AAAS	Amer. Ass'n Adv. Science	6	4
AERA	Amer. Ed. Research Ass'n	8	5
MAA	Math. Assoc. of America	6	6
NCTM	Nat'l Council Teachers of Math	6	9
ACM	Association for Computing Machinery	4	2
PDK	Phi Delta Kappa	3	8
	Executive/Editorial Responsibility	21	8
		59	49

Table II(d)

PUBLICATIONS OF DISE PIs - FY 1980

	59 AWARDS NO.	49 DECLINES NO.
Books	25	11
Book Chapters	34	21
Research Journal Articles	41	25
Applied or Non-Research Journals	25	26
No Publications	5	5
Textbooks and Curriculum Materials	0	15
Film, Filmstrip, TV	1	1
Tests	0	2
No Information Available	1	6

The principal difference (not surprising) that I infer from the data is the greater commitment of the RISE investigators to research for the sake of research and the clear commitment of the DISE investigators to the production of a product or procedure that will be useful. This might seem to be obvious from the fact that, after all, one group did apply to the research program while the other applied to the development program. It is interesting that this difference is reflected in membership in professional organizations and in the institutions of the PIs.

I also infer from the proposals I have read and the data presented here that the people interested in development do not have as broad a grasp of relevant research as those preparing to embark on research projects. This, too, is not surprising but raises the question of how we can better feed research results into the thinking of developers.

Implications for Education and Training

The results combined with observations and discussions suggest the following to me:

- Future research workers should spend at least part of their training time working with a development project in order to appreciate the nature of the development process.
- Greater numbers of research theses should be conducted in the context of development projects.
- A specific curriculum and training program should be designed for students who are interested in becoming authors of instructional materials. My hope would be that these people would be excellent in a discipline (e.g., math or physics) and have a flair for and an interest in expressing themselves in various ways.
- The training of authors should include an intensive introduction to the literature of cognitive science and research in science education. This should not become another credentials barrier, but rather a way to increase the flow of knowledge and ideas from the research community to the development community.

Rationale for a Closer Interaction between R&D

Characteristics of Development in Science Education

Development in science education has the goal of providing (a) new methods of instruction, (b) up-to-date instructional materials that reflect the latest scientific knowledge as well as changing ideas of what knowledge is most worth having, and (c) applications of the new information technologies to science and math education. While a development may be influenced by research results, typically a development idea is based upon an intuitive, passionate vision of what the educational experience ought to be. Development, then, is driven by (1) a perceived need, (2) available resources, and (3) an intuitive vision.

Characteristics of Research in Science Education

The goal of the RISE program is a fundamental understanding of the processes that lead to or inhibit knowledge of science, its methods, and its limitations. What variables and relationships come into play as a person travels the path from initial attention and interest to knowledge and skill in science? What factors limit the learning process or divert the student from further investment of time and effort in that pursuit?

Research is driven by (a) curiosity, (b) our implicit and explicit theories of human development and education, (c) available methods of investigation, (d) current trends in research, (e) perceived need, and (f) our current state of knowledge. The methods of research are influenced by available technologies (e.g., computers for data analysis) and the range and kinds of objects and events that are available for study (e.g., persons with split-brain surgery). Later I will make the point that DISE projects give the RISE worker the opportunity to study new and interesting events exactly because they are often designed on the basis of a novel, intuitive vision of the educational process.

Effect of Research on Development

In my judgment, we do not yet have a sufficient body of research results in science education to enable us to design instructional materials primarily on the basis of such knowledge. What then is or should be the effect of research on development? Before I attempt to answer, let me make a small digression. I take the position that it is impossible to avoid the influence of theory on research. We are faced with a huge number of variables, and so we must have some method of selecting which variables we will observe, measure, record, and interpret. This decision must have some basis. I argue that the basis is either our intuitive implicit theories of how people learn or our explicit theories of learning. The difficulty with implicit theories is that, because they are hidden, they interfere with an orderly and systematic discussion of issues.

Conversations about educational alternatives are often what has been called "the dialogue of the deaf" because the participants are using different implicit theories, different internal models of the educational process. As a result, I--and others--propose that explicit theory building is important for the advance of knowledge of the process of science education.

Explicit theories that are based upon observation and experiment have an effect upon new research by encouraging studies that explore and test the theories. These same theories have an impact upon development by influencing the world view of the developer. As a theory such as that of Freud or Piaget is absorbed by the members of society, it alters our internal model of the world. As a result we change the way we observe and interpret student behavior, the way we interpret elements of the curriculum (e.g., we might recognize that a task requires formal reasoning ability before a student has left the concrete reasoning stage), and the kind of learning and teaching environment of which we approve. This alteration of world view then influences the kinds of developments that we think are desirable. For example, under the influence of Piagetian research, a number of investigators have undertaken the design of instruction to assist the student in understanding scientific concepts using concrete reasoning.

The above argument implies that, at the present time, we cannot easily design instructional materials and instructional environments on the basis of research principles alone. This does not mean that laws, principles, and relationships are not established by research. Rather, there are so many uncontrolled factors, so many possibilities for counter-intuitive effects, that a simple, linear R&D model of development is liable to run into difficulty. Art, craft, intuition, and tradition are still central to the development process. Research primarily changes the filters through which we view the educational process.

Need for a Broader Range of Observations in Research

As we modify the effects of educational variables (e.g., teaching methods, class size, and instructional media) results on achievement are usually disappointingly small. Many reasons have been offered for this lack of effect, and I would like to focus on one possible explanation. It may be that we have not explored educational effects across a sufficiently broad range of observational domains.

Astronomy. In order to clarify what I mean by this, let me start with astronomy as an example. Until recently our view of the nature of the universe was limited by our observations with visible light that could penetrate through the atmosphere to our telescopes. During this century this "observational window" has been opened wider and wider. As we have developed our detection technology, cosmic rays, radio waves, infrared radiation, ultraviolet radiation, x rays, and other parts of the electromagnetic spectrum have become "visible" to our instruments. As our detection technology has become more and more sensitive and able to filter signal from noise, we have uncovered radio stars, quasars, pulsars, the background radiation field apparently left over from the "big bang" of creation, and other novel phenomena. As a result of the broadened range of observation, long-held theories have been challenged and replaced by a dramatically different view of the universe. These new views require the union of evidence from astronomy and fundamental particle physics. I propose that we need a similar broadening of our range of observations in educational research. From where might these new observations come?

Behavioral and Social Science. Cognitive Science. Many research findings and observations have implications for a theory of learning and instruction. Artificial intelligence work with computers has provided analogies, new terminology, and simulations of human thinking processes. Even the differences between machine performance and human performance give us new insights to ponder. Work with animal learning, handicapped people (e.g., split-brain research), unusual people, neural responses, neural growth as a function of experience, EEG patterns, mental rotation of images, twin studies, and problem-solving behavior are among the research areas that are providing useful knowledge to the educational research community. Recently novel techniques have been developed to permit us to observe specific, localized changes in brain function in response to a variety of stimuli, e.g., immunofluorescence and positron emission tomography (PET). Many of these studies show pronounced effects. They also challenge us to understand how these effects become integrated into learned performance.

New Observations from Educational Studies

The following are some kinds of novel studies in educational research that might broaden the range of observations in such a way as to show pronounced effects on learning: unusual relationships between a child and a parent or other adult (e.g., the cases of the physicists Fermi and Einstein), cases of unusual schools or teachers, cases of unusual environments such as computer-based learning environments, and, finally, cases provided by the DISE projects. Many of the DISE projects provide examples of novel environments that may offer interesting effects upon learning if properly studied by skilled research workers. Presently only a few projects such as those headed by Dr. Lillian McDermott at the University of Washington Physics Department have formal educational research conducted in the context of a development project.

Hidden Variables

The result of conducting research in the context of a development project is that we might uncover important variables that were previously unnoticed or dismissed for some reason. My best example of this is the discovery of the effect of "wait time" by Dr. Mary Budd Rowe of the University of Florida. Working with Dr. Robert Karplus' Science Curriculum Improvement Study Project, she noticed that in some classes, the class statements of students were logical, reasoned, and made use of evidence from laboratory work and past personal experience. Class discussion proceeded at a measured pace. In other classes, the students' statements were impulsive and off-the-top-of-the-head. Students ended their statements with a rising inflection, as if asking, "Am I right?" Dr. Rowe thought she noticed that in the classes with reasoned conversation the teacher would wait 3-5 seconds after asking a question before going on if a student could not respond immediately. In these classes, the teacher also would wait after a pause in a student's response before going on to another student or beginning to speak her/himself. Dr. Rowe then conducted some more controlled studies in which she manipulated wait time and found that this process indeed affected the quality of class conversation. She has gradually built these studies into a theory of fate control--how a sense of personal causation is a factor in life and learning.

My personal hunches of possible other areas that might result in new variables in education are as follows: The intentions of the learner may seriously affect what is learned. The signals transmitted to learners by the social network surrounding them may control their behavior in the learning context. One's aesthetic or emotional responses to material may have a pronounced effect. The whole area of what makes things interesting, compelling, fun, curiosity-provoking, or worthy of intense sustained effort, needs further investigation. There is evidence that faulty mental procedures generate a great deal of difficulty in learning math and science. And the time sequence of neural responses to learning stimuli may generate novel relationships for us.

Potential Impact of Development on Research

In summary, if development projects are taken seriously as a context for research in science education, the following may result: The implicit and explicit vision of the developer opens up new possibilities to the research investigator. The development trial sites create new events to study and may suggest implicit theories of education to be made explicit and studied. The researcher may have an opportunity to test explicit theories, thus benefiting from closer contact with the "real world."

Barriers to Greater Interplay between Development and Research

I offer the following speculations as to the barriers that separate our development and research communities:

There is a lack of common theory or theories. If our theories of education are largely implicit, we cannot easily organize our agreements and disagreements and create an agenda for resolving them. We tend to talk past each other as our utterances are generated by internal models unknown to our audience. Research workers tend to generate a specialized language that is usually not familiar to the developer. The language barrier makes it difficult for the developer to be guided by the ideas of the latest research. The two communities (in my judgment) differ as to what lines of effort are interesting, fruitful, and feasible. And there is implicit uncertainty as to the proper level, the proper scale, of investigation. The funding source (RISE) is often hesitant to support "research" which looks too much like project evaluation or open-ended exploration.

A speaker once observed that physics deals with a huge number of particles but only a few variables. When we try to understand an individual, we are dealing with just one person but a huge number of variables. This array of possible variables that can come into play in a given performance makes life very difficult for the research worker who attempts to explain and predict human behavior.

The two communities--science education research and development--are kept apart by their separate formal societies and publications.

There is a real cost in time and money to interact with a network of people across the boundary between research and development. In the modern world, I sense that this time and money pressure is a real barrier to greater cross-discussion.

Finally, I would propose that if we really want developers to know more about research findings and to include them in their work, we should develop a curriculum for developers that will introduce them to the field, provide them with a basic vocabulary, and alert them to some of the principal thinkers. In my own experience, a primitive curriculum of this kind developed for a Doctor of Arts project at the University of Illinois at Chicago Circle (and funded by the forerunner of the DISE program) was very effective in starting a life-long involvement with the research literature on the part of students who intended to be future developers in a particular scientific discipline.

RELATING RESEARCH AND DEVELOPMENT IN EDUCATION

Susan F. Chipman
National Institute of Education
Washington, DC 20208

Dr. Susan F. Chipman is Assistant Director of the National Institute of Education for Learning and Development where she directs a division of 14 professionals. She holds degrees from Harvard in mathematics and managerial economics, decision and control. Her Ph.D. degree, also from Harvard, is in experimental psychology. Dr. Chipman's major research interest is cognitive psychology and cognitive development, with emphasis on the processing and representation of visual information. She is the author of many writings on visual pattern perceptions. With Dr. Erik McWilliams of SEDR she was co-director of the Research on Cognitive Processes and the Structure of Knowledge in Science and Mathematics Program, 1977-78, funded jointly by the National Institute of Education and the National Science Foundation.

Relating Research and Development in Education

At the National Institute of Education (NIE), the relationship between curriculum development and research is a topic with a hypothetical status since NIE has almost no new curriculum development activities. For a 5-year period extending through this year (FY 1981), the National Council on Educational Research, NIE's policymaking body, set a policy which is very discouraging of curriculum development activities. I will quote the key phrases in this policy:

> In contribution to the improvement of instructional programs, NIE's major roles, in order of priority, shall be: (1) sponsoring the conduct, synthesis, and dissemination of applied research on issues of curriculum and instruction, (2) sponsoring efforts to strengthen, facilitate, or coordinate others' work in improving instructional programs, and (3) sponsoring the prototypic development of new instructional programs.

With the exception of the quoted policy of the National Council on Educational Research, the opinions expressed herein are those of the author and do not represent the official opinion or policy of the National Institute of Education.

The only major exception specified in this policy that would permit a full-scale development was a direct relation to the achievement of equalization of educational opportunity, of which needs in bilingual education were cited as a specific example. Development activities designed to meet other nationally recognized needs or to take advantage of unique opportunities require the review and concurrence of the National Council on Educational Research. In addition, the policy specifies that even full-scale development ordinarily will not include sponsorship of the dissemination and implementation of the products.

To my knowledge, no full-scale development has been undertaken during this period. Some of you will be familiar with the prototypic activities that the Program on Teaching and Learning has sponsored. One example was the development of prototypic curricula demonstrating the creative use of hand-held calculators in the classroom. More recently, there is the related joint National Institute of Education-National Science Foundation (NIE-NSF) program supporting the development of prototypic mathematics curriculum materials for microprocessors.

The current policy on development activities expires this year. I do not know if the policy is likely to change. The considerations which led to the adoption of this policy are contained in a report, "NIE's Role in Curriculum Development: Findings, Policy Options, and Recommendations." I suspect that the conditions which led to this policy have not changed substantially. In any case, the present budgetary situation means that a change in policy would have little practical effect. We cannot afford the immense expense of a full-scale curriculum development within the limits of our current (Carter Administration) budget. Any such activity would require a special addition to the budget.

In the past, NIE has supported many curriculum development projects, some of which continue. The catalog of NIE products that was issued a few years ago is over 2 inches thick. Most of these development activities took place within the educational laboratories and centers that NIE supports with about $30 million each year. For example, the research center at the University of Wisconsin developed a mathematics curriculum, Developing Mathematical Processes (DMP), that has been completed and published. CEMREL, a laboratory in St. Louis, continues to develop the CSMP (Comprehensive School Mathematics Program). CSMP, one of the survivors of the "new mathematics" is showing promising evaluation results. Students in the program, including low-income inner-city children, perform as well as students in conventional curricula on standardized tests of mathematics achievement. In addition, they perform significantly better on special tests of mathematical understanding and problem solving. Unfortunately, the curriculum, which was designed to develop fundamental mathematical concepts such as "function" and "relation," calls for major investments in implementation if it is ever to be widely used. The material in grades 4, 5, and 6 tends to be impossible for teachers to understand if they have not worked through the materials for the earlier grades. CEMREL also developed a curriculum for gifted secondary school students, Elements of Mathematics. In other institutions some mathematics curriculum projects were terminated. In addition, there was a wide variety of reading curriculum development projects in the labs and centers. Diverse other projects existed. For example, CEMREL also developed a curriculum in aesthetic education.

Ways of Relating Research to the Curriculum

While we at NIE have not been in the position to relate development to research, we have been able to relate research to development. During a site visit to the mathematics group at the Wisconsin center, we suggested that they might design a research agenda for themselves by identifying the units in the DMP curriculum which are relatively less successful in teaching the concepts they are intended to teach. Because the curriculum involves detailed testing for mastery, this information is readily available. Research projects could then be undertaken to identify the sources of conceptual difficulty. I believe that the research projects in which this group is now engaged were influenced by such an examination of difficult spots in the curriculum. Since NIE takes a relatively activist approach to research management by issuing Requests for Proposals (RFPs) to do research specified by the agency, we have also applied this same strategy in selecting topics for some of our RFPs: calling for research on the acquisition of concepts which are known to be generally difficult points in the conventional mathematics curriculum. At this moment, in fact, we are calling for clinical studies of mathematical learning difficulties in high school algebra and geometry. In this instance, we have left the specification of the particular concepts under investigation to the researchers. This kind of relationship between the topics selected for research and the curriculum is also something that we look for in research grants applications. It is one way to demonstrate the sensitivity to educational practice that is called for in our grants announcements.

Development in Response to Research Progress

How would we relate development to research, if we were in a position to undertake development activities? When is a full-scale curriculum development project justified? And how does it relate to research? There are two major elements that enter into any curriculum development project. One is the substance which is to be taught. The other is notions about strategies and techniques for teaching that substance. A major change in our state of knowledge and belief about either of these two elements would seem to be what justifies a new curriculum development activity. Advances within the substantive field being taught may result in changed opinions about the key organizing ideas which we would like to see transmitted to beginning students. A drastic change in government may require the development of new texts in history and social science subjects to conform to the new ideology. This kind of justification for a new curriculum, along with the desire to introduce a new subject into the curriculum--for example, computer programming--is probably most familiar.

But there are other equally valid reasons to undertake a new development activity. There may be a revolutionary change in our understanding of the nature of the skill or knowledge to be taught. For example, I believe that research on reading comprehension has brought us to such a drastic change in the detailed and precise understanding of the goals of reading instruction. Quite a few years ago, NIE organized a very large planning conference for its activities in reading. From this conference emerged the judgment that research in reading comprehension should be given highest priority, funded in preference to research on the perceptual, phonetic, and decoding aspects of reading that had been predominant. Since that time, NIE has been making very large investments in reading comprehension research both through individual research grants and through a competitive research contract which established the Center for the Study of Reading for a 5-year period with funding of about $1.5 million per year. The size of this investment has probably been large enough to change the course of research activity in the two basic research fields most relevant to this program: cognitive psychology and linguistics. It was also a fortunate circumstance that basic research psychologists were ready to take on the type of complex problem that reading comprehension represents. The interaction of NIE's investment with the general spirit of the times has resulted in a great concentration of research effort on reading comprehension: the National Institutes of Health (NIH), NSF, and the Office of Naval Research have all been supporting some research which contributes to improved understanding of reading comprehension.

Of course, research is never finished. Each advance generates new questions, possibly in geometric progression. But the contrast is stark between the detailed understanding of the processes of reading comprehension that is coming from this research and the view of reading comprehension represented in the writings of reading educators that I reviewed when I came to NIE 5 years ago. Even those who were known for their emphasis on the importance of comprehension in reading instruction seemed to suffer from a total absence of ideas about what exactly is involved in successful understanding. They seemed to offer only exhortations about the importance of understanding to either teachers or students. In contrast, today we have quite a detailed knowledge of the linguistic devices that are used to signal relations between sentences, such as the fact that an object now being mentioned has been discussed earlier in the passage. Just a few short years ago, linguistic analysis was confined to single sentences. Today, it is possible to write a computer program that can do a reasonably good job of locating the main idea in a paragraph, a task that many students cannot manage effectively. Detailed mathematical modeling of the eye movements of skilled readers allows us to draw reasonable conclusions about which information skilled readers are using to integrate their understanding of the text. The research is very rich. Probably the time is ripe to attempt to transform this growing understanding of what skilled readers do, as they comprehend a text, into a curriculum that will train the less skilled to do likewise. Unfortunately, it is unlikely that NIE will have the resources to support even this development activity.

Recently, a highly successful conference presented the highlights of this research to representatives of the publishers of the major reading textbook series. We hope that this will result in improved comprehension instruction in their new editions.

It is interesting that few of us consider that being an expert reader should make you an expert teacher of reading. The view has been otherwise in science instruction. I think it is possible, however, that research of the sort that has been supported in the joint NIE-NSF Program on Cognitive Processes and the Structure of Knowledge in Science and Mathematics, research which continues to be supported by both agencies separately, will result in an equally profound revolution in our understanding of the processes of science learning. One day we may feel a compelling need for new science curricula which represent an entirely new approach to teaching.

Such results should not be expected instantly. Research is inherently analytic. Teachers are always complaining that researchers tend to take on very small and restricted questions. I would hope that science teachers--at least those who have been researchers--would appreciate the fact that this is the nature of researchable questions, not the perverse nature of researchers. Consequently, we need substantial clusters of related research projects before it is reasonable to expect or call for an impact on teaching. Today there are just a few topics--early number concepts in mathematics, simple mechanics problems in physics--which are attracting enough research activity to show genuine promise of advances in understanding. As the research communities grow, it may be reasonable to consider the option of research centers, comparable to the Center for the Study of Reading, to foster an integrated body of research drawing upon the expertise of several disciplines. However, a research community must be quite large and well developed to warrant the gamble that a single bidder will be able to gather the necessary talent in one place to form a high-quality research center. Coordinated effort is no substitute for quality effort in research.

Incidentally, the NIE experience with curriculum development does provide some experience concerning the extent to which one can expect research to be integrated into an ongoing curriculum development effort. I believe that this was one purpose behind the government support of curriculum development in the context of the laboratories and centers: to provide a level of support that would make it possible to integrate research into the development process. According to reports that I have heard, highly qualified people were indeed hired to pull together relevant research knowledge at the time the projects were initiated. However, the opportunity for interaction soon closed off as the need to arrive at a completed product made changes in either basic premises or even detailed teaching ideas less and less welcome. This seems inevitable. Perhaps a detailed research investigation of a difficult point in a curriculum, as suggested above, could yield a specific fix, but it might equally well lead to a challenge of one of the basic premises on which the curriculum is built. In development, it seems that you run with the knowledge you have at the outset. Therefore, you should be reasonably satisfied with the state of the necessary knowledge before initiating a major development activity.

<u>Relating Psychological Research to Curriculum Development</u>

Some of you may have noticed that, although I was introduced as an experimental psychologist, I have said little about the relationship of basic research in psychology to curriculum development. Of course, research in psychology is one of the major sources of ideas about modes of learning and effective ways of teaching. This is true whether or not curriculum developers realize that it is true and whether or not they make a deliberate effort to incorporate ideas from psychological research in their development activity. Over a period of time, ideas that were once esoteric research become commonplace and commonsense. Today, for instance, Freudian ideas are almost inescapable. They pervade literary criticism, historical discussions, and Ann Landers' advice columns. Watson, and Skinner after him, wrote for the ladies' magazines. Barry Brazelton, a pediatrician-researcher who is in close communication with researchers investigating cognition in infancy, writes a regular column for parents. Thus, the paths by which ideas are communicated are often indirect rather than straightforward and academic.

There are other sources of ideas about learning and teaching. The most important is probably the accumulated experience of many generations of efforts to teach a subject. Reading instruction, for example, should probably be considered very difficult to improve because it has been going on for a very long time. A shortcoming of this source of knowledge about learning is that usually only certain groups of people have been educated, and there has been a great tolerance for failure in teaching. Particularly in mathematics and science, education has been as much a process of selection as a process of instruction. Today, we want to develop instruction that will work for a broader range of the population.

Probably the major source of the traditional teaching ideas as well as a continuing source of ideas is introspection into the instructor's own thinking and learning processes. The instructor or curriculum developer is likely to be an unusual student, however, a strong and thriving survivor of the selection process. Therefore, these introspections may not be valid for the typical student. The same is true of preferences in learning experiences. Perhaps the period of enthusiasm for discovery learning should be attributed to a combination of such personal preferences with a rationalization drawn from cognitive developmental psychology. Aside from problems arising from the atypicality of the person doing the introspection, there are problems created by the fact that only certain kinds of psychological processes and knowledge are accessible to introspection. Science educators interested in "cognitive process instruction" are beginning to recognize that the expert scientist has a great deal of knowledge in the form of conceptual relationships and problem-solving skills that does not appear in the overt instruction devised by that scientist.

Ironically, it is this same kind of knowledge that I believe psychologists have to offer in science education, not the kind of knowledge that psychologists ordinarily put in their courses or their textbooks. Psychologists--that is, the elite of productive research psychologists--know how to investigate psychological questions. They can't tell us much about developmental stages in major scientific concepts or about how scientific concepts are learned or most effectively taught. Such topics have not been the subject of much research activity. But psychologists do know how to go about investigating science learning. They have a repertoire of conceptual distinctions and experimental techniques that can be very effective. In fact, I think we shall soon see very exciting results from the research programs of those few strong psychologists who have chosen to apply the power of their own scientific tradition to the problems of science learning. Fortunately, it does seem possible to attract some of the strongest psychological researchers of the present generation to these problems.

It is important to recognize that special research must be done on the questions of science learning. Since the situations and kinds of behavior that have been researched in psychology are usually quite different from those which pose educational problems, there is quite a lot of risk in making generalizations without undertaking research to test the validity of the generalizations. As a specific example, Professor Wirszup's recommendation of the European-style curriculum, in which the instruction that we give in one year is spread out over several years, reminded me of one of the classic findings of experimental psychology: "distributed practice is better than massed practice." That is, psychological research might be taken to support Professor Wirszup's opinion. However, this research was done on the learning of nonsense syllables over short periods of time, which seems quite different from the learning of geometry. I, for one, would hesitate to make the generalization.

The background of research on nonsense syllables might help us design a good analog experiment with geometry concepts. If we found the generalization to hold true, it might still be the case that the underlying mechanisms for the two phenomena are quite different, so that the generalization is really only metaphorical. In the same way, it is now becoming evident that the patterns of thought to which Piaget gave the name "formal operations" do not characterize an individual thinker so much as they characerize a stage in the mastery of any particular conceptual domain. Piaget's synthetic genius is not diminished by pointing out that the patterns he observed do not necessarily contain the detail required for useful guidance to instruction.

Another important point to remember about psychological theories is that they are partial, isolating some aspect of the whole for close analysis. Trying to apply a single psychological theory as if it covered all the territory is likely to lead to disaster. Many of you may have heard that behaviorism is pass;e, that the fashion has changed in psychology. It may seem that this is the kind of revolution in our understanding of human learning that might justify abandoning any curricula based on the former view. It is true that the focus of current research activity in psychology has radically changed, but that doesn't mean behaviorism was wrong. Skinner, in his book Verbal Behavior, said that complete sentences are reinforced. My generation has chosen to wonder what in the world a complete sentence is that it is an entity that can be reinforced. Behaviorism dealt primarily with the motivational aspects of learning, largely ignoring the constraints on what could be learned. Cognitive psychology deals primarily with the structure and organization of learning, with those constraints, and largely ignores motivational aspects of learning. Neither is wrong. Each is a partial view.

When behaviorist principles were applied to curriculum development, it led to the proliferation of small objectives, in imitation of the way Skinner trained his pigeons to play ping-pong. In general, it is probably a good idea to specify objectives. But it is very important that small objectives actually add up to give the desired large objectives. If your understanding of the skill you want to achieve is so poor that the specified partial objectives miss the point, you might be better off muddling through in an undirected fashion, in which case some activities might contribute to the important objectives that you have been unable to specify. I think that most objections to behaviorist curricula arise from the subjective judgment that the specified objectives fail to capture the true nature of the subject matter. In the behaviorist approach, the analysis of the skill into trainable components was an art or craft sometimes called task analysis. Today, it is becoming a subject of scientific investigation.

There is an interesting way in which basic psychological research may come to meet the subject matter expert in curriculum development activities. It seems possible that some of the research now exploring the nature of expert knowledge in science will lead to general techniques for extracting and representing the knowledge that people have. Such techniques might make the subject matter expert's participation in curriculum development activities much more efficient and productive. Eventually, we might also develop an instructional technology which would convert such descriptions of knowledge into effective teaching procedures. (Alternatively, we might embody that knowledge in computer programs and develop an entirely different set of goals for human education.) Of course, it is the promise of achieving insight into the general nature of human knowledge that makes this research attractive to good psychologists. If such great accomplishments occur--or even before they are complete--basic researchers in psychology can be expected to move on to other problems. Meanwhile, if science educators can appreciate the fact that psychology is a basic science in its own right with its own questions, historical directions, and current research priorities--not a field which exists solely to serve the needs of education, management, or other fields of activity in which learning and performance have practical importance, a useful period of collaboration can probably emerge. Since an individual lifetime doesn't have room for very many serious research investigations, many of those who are attracted to problems in science education will spend their research careers working on those problems. I am quite certain that reading education is benefiting from having been the subject of a fashion in psychological research. The potential is there for science education as well.