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ABSTRACT

A brief statement of the importance of a liberal education for all teachers is followed by twelve guidelines for the planning, implementation and evaluation of programs for educating prospective secondary school mathematics and science teachers. Each guideline contains a brief rationale, describes the expected skills, and suggests strategies for developing desired competencies and attitudes. The guidelines concern humaneness, societal issues, nature of science and mathematics, science compentencies, mathematics for science teachers, basic mathematics competencies, algorithms and computers, modeling in science and mathematics, communication of science and mathematics, learning conditions, materials and strategies, and continuous learning. Four standards that each teacher-training institution should satisfy, and supporting materials prepared by the project committees or regional working groups, are included. Lists of persons and organizations involved in the guideline preparation are appended. (AL)

GUIDELINES AND STANDARDS

American Association for the Advancement of Science and
National Association of State Directors of Teacher Education and Certification

Recommendations of the Project on the

Education of Secondary School Teachers of Science and Mathematics

sponsored by the

AAAS Commission on Science Education

and the

National Association of State Directors of Teacher Education and Certification

and supported by the

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CONTENTS

Foreword
Introduction —1
To Whom Is the Report Addressed? —1
The Organization of the Recommendations —3
Liberal Education —4
Guideline I. Humaneness —5
Guideline II. Societal Issues —7
Guideline III. Nature of Science and Mathematics —10
Guideline IV. Science Competencies —13
Guideline V. Mathematics for Science Teachers —19
Guideline VI. Basic Mathematics Competencies —21
Guideline VII. Algorithms and Computing —26
Guideline VIII. Modeling in Science and Mathematics —28
Guideline IX. Communication of Science and Mathematics —32
Guideline X. Learning Conditions —34
Guideline XI. Materials and Strategies —36
Guideline XII. Continuous Learning —40
Standard 1. Responsibility —42
Standard 2. Teachers as Models —44
Standard 3. Performance Criteria —46
Standard 4. Recruitment and Retention —48
Epilogue —51
Appendix A. Implementation —52
Appendix B. Unified Science Model and Related Science Teacher Competencies —55
Appendix C. Selected Examples of the Aspects of Models Listed in Table 2. —61
Appendix D. The Junior High School Teacher of Mathematics —63
Appendix E. A Model for Teacher Candidate Evaluation —65
Appendix F. Project Participants —67
Appendix G. Professional Organizations and Groups Reviewing the Guidelines —75
Appendix H. Committee Members —76
Notes—77

FOREWORD

During the past decade the American Association for the Advancement of Science (AAAS) has played an important role in the development of guidelines for the preparation of elementary and secondary school teachers of science and mathematics. Since the publication of *Guidelines for Preparation Programs of Teachers of Secondary School Science and Mathematics* in 1961, AAAS has also been involved in the preparation of two guideline documents for the preservice science education of elementary school teachers, one published in 1963 and the second in 1970.

Since 1961, there have been extensive changes in the science and mathematics curricula in secondary schools and changes in the secondary school system itself that have necessitated changes in teacher education programs. It was to reflect some of the new developments that the AAAS Commission on Science Education, in cooperation with the National Association of State Directors of Teacher Education and Certification (NASDTEC), undertook the task of preparing new guidelines for preservice education programs of secondary school science and mathematics teachers.

Two preliminary conferences were held to review current teacher education programs, to consider the trends in science and mathematics education and to discuss the needs and problems to which the new guidelines must speak. Persons participating in these conferences, as well as in all other aspects of the project, represented the various secondary school science and mathematics curriculum projects, the disciplines of science and mathematics, science and mathematics education, state departments of education, secondary schools, and professional organizations.

Four committees* were established by the project's Advisory Board to consider the reports of the preliminary conferences and to develop specific statements concerning 1) the nature of science and mathematics and implications for the teaching of science and mathematics, 2) the necessary preparation of the mathematics teacher in mathematics and other areas, 3) the necessary preparation of the science teacher in the areas of science and mathematics,

*Names of committee members are listed in Appendix H.

and 4) the strategies for the teaching of science and mathematics. The recommendations of these committees were combined into a preliminary report of the project, which was sent to some 450 persons for review and comment.

Persons receiving the preliminary report were invited to attend one of three regional conferences to discuss the recommendations. In addition to personnel representing institutions of higher learning at least one member from most of the 50 state departments of education participated in these final three conferences. Recommendations made at the three conferences were considered carefully in preparing the final report.

Those using these guidelines will observe a marked difference in the tone of the guidelines on science competencies and on mathematics competencies. This resulted from different points of view taken by the members of the two committees that prepared those particular guidelines and by the scientists and mathematicians who participated in the review conferences. The mathematics committee felt that it was important to spell out quite specifically what mathematics competencies the prospective teacher should have. The science committee preferred to paint with a broader brush and to leave the details of science content to the faculties of the teacher education institutions.

Although it is impossible to forecast with confidence the direction science and mathematics education will take in the next decade, it is clear that change is occurring: change in the administrative structure of the school, change in our understanding of the teaching-learning situation, change in our society. The guidelines must be able to accommodate these changes. It is always the hope in such ventures, that the guidelines will encourage flexibility and diversity among teacher education programs, but still provide some structure and direction.

"Anyone in the field of teacher education today who is not impatient with the status quo and eagerly seeking new solutions is more insulated from reality than he has any right to be."[1]
John W. Gardner

It will be disappointing if this report is not somewhat controversial. Controversy initiates discussion. Discussion prompts evaluation of existing situations. If the report stimulates responsible persons to give serious thought to the role, the value, and the purpose of teacher education programs for future science and mathematics teachers at the secondary school level, then it will have served a purpose. If the report helps give direction to the teacher education programs and is useful in other ways as institutions attempt to evaluate their programs, the funds invested in this project will have been well spent.

The report is the product of hours of meetings, discussion, and plain hard work by many persons. The names of those who gave of their time and abilities, are listed in Appendix F. Special credit must be given to the members of the writing committees and to the Advisory Board for their special contributions.

David H. Ost, Coordinator
Teacher Education Project

INTRODUCTION

The National Science Foundation, during the 1950s and 1960s, supported the development of a full complement of new science and mathematics courses for the secondary school, and at the same time supported a massive program of institutes designed to reeducate teachers in both subject matter and pedagogy to qualify them to use the new materials effectively. However, the preservice education of science and mathematics teachers was not substantially changed during this time. Programs for the preparation of science and mathematics teachers have typically been derived from the existing school curriculum. As a result, teachers are prepared to teach what is already being questioned in the light of current educational insights and research. Entering teachers are often tradition-bound from the onset of their careers and too often find it difficult to adjust to new educational demands.

New directions for science education for the 1970s are already widely debated in the professional literature, the public press, and in the journals representing academic disciplines. There is consensus that the schools must keep pace with cultural change, and that a mismatch may now exist between science and mathematics education and the condition of society. This condition demands that teacher education institutions examine the degree to which their programs reflect progress in science, new emphases in education, and changes in society. It also suggests an urgent need for new guidelines in teacher education.

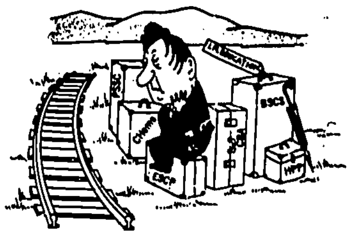
"The pieces of educational revolution are lying around unassembled."[2] John W. Gardner

These guidelines for the education of secondary school teachers of science and mathematics have been developed to assist in the reexamination of existing programs and to provide guidance for innovation. The recommendations are not developed for blanket adoption, and it is expected that they will be adapted to local conditions and problems. The guidelines are addressed to the preservice education of science and mathematics teachers, but the importance of continued education and a lifetime commitment to study and research is emphasized throughout the report.

"Civilization is a movement . . . not a condition, a voyage and not a harbor."[3] Arnold Toynbee

TO WHOM IS THE REPORT ADDRESSED?

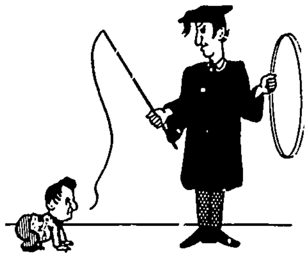
These guidelines are offered as resources for all persons interested in the preparation of teachers of secondary school science and mathematics. They should be of special interest and value to the groups listed below, as they consider the problems of teacher education. The questions directed to each group suggest specific aspects of the teacher education program with which the group should be concerned.



Science and Mathematics Faculties

- What types of science and mathematics experiences should the future teacher have?
- What specific science and mathematics competencies should a new teacher have before he enters the secondary school classroom?
- Is the prospective teacher given the opportunity to relate science, technology, and society?
- Does the future teacher have an opportunity to develop an appreciation of the role science and mathematics have played in the shaping of Western thought?
- What responsibilities do the college mathematics and science faculties have for continuing to improve the mathematical and scientific competencies of the practicing secondary school teacher?

Professional Education Faculties



- Do the teacher education programs provide opportunities to relate a discipline-oriented education to a cross-fields approach increasingly demanded by the problems of our society?
- Does the future teacher have the opportunity to learn about the psychology of learning science and mathematics?
- By what means are positive attitudes toward self-evaluation and continuing education developed?
- How does the program provide motivation for increasing professionalism among future teachers?

School and College Administrative Personnel—State, Regional, and Local

- To what extent can a program have structure without rigidity, and flexibility without disorder?
- What is the role of administrators in fostering relevant and challenging continuing education programs?
- What means can be provided to stimulate self-evaluation and continued review of the individual teacher's competencies, skills, and attitudes? How is this related to certification?
- To what extent does the college or university bear responsibility for developing in prospective teachers those attitudes and skills that foster self-evaluation and self-renewal? To what extent do the schools share this responsibility?

Professional Organizations

- What kinds of experiences are essential for science and mathematics teachers involved in continuing education programs?
- What unique or special types of experiences are required in the education of science and mathematics teachers?

- What can professional organizations do to improve science and mathematics education for the future teacher as well as the secondary school student?

National Council for Accreditation of Teacher Education (NCATE)

- Has the institution critically examined these Guidelines and considered their relevance for teacher education curricula?

THE ORGANIZATION OF THE RECOMMENDATIONS

The report begins with a brief statement on the importance of liberal education for all teachers. This is followed by twelve guidelines for the planning, implementation, and evaluation of programs for the education of secondary school teachers of mathematics and science. These guidelines include brief rationales, descriptions of skills needed by future teachers, and suggested strategies for helping future teachers acquire the desired competencies and attitudes. The twelve guidelines are followed by four standards that each institution should satisfy.

Supporting materials prepared by the project committees or working groups in the regional conferences are printed in the appendices. Also included as appendices are implementation suggestions for the guidelines, a list of the more than 300 individuals who contributed to the development of the guidelines, and a list of the 17 organizations that cooperated by naming a liaison person to provide counsel and communication during the development of the guidelines.

LIBERAL EDUCATION

All teachers should be liberally educated persons. Through an education that liberates, future teachers will be best prepared to meet the challenges and problems of teaching. Education in science and mathematics is an essential part of liberal education and the guideline descriptions of the kinds of experiences that the teacher education institution should provide for the preparation of secondary school teachers of science and mathematics are believed to be expressed in the spirit of liberal education. It is of critical importance for the liberal and professional education of the secondary teacher of science and mathematics, for example, to study philosophy and psychology of science and mathematics; to have interdisciplinary experiences that will enable him to comprehend the issues related to science, technology, and society; to be competent in oral and written communication; and to develop commitment to a lifetime of learning. These kinds of experiences are all a part of liberal education.

But this is by no means all of liberal education, and, although the guidelines do not attempt to describe other essential parts, particularly in the arts and humanities, it is expected, and indeed it is essential that every teacher education institution provide a broad education for secondary school teachers of science and mathematics. Certainly no state department of education will certify any teacher without evidence that the teacher is a liberally educated person.

Many excellent models of undergraduate programs of liberal education exist and new models are being developed. Each institution is urged to reexamine its liberal education program with reference to these models and to consider how the science, mathematics, and professional preparation of teacher education programs can be related to, and be used to strengthen, liberal education. There is no specific guideline related to liberal education, but no person and no institution should interpret this omission as assigning this essential aspect of teacher education a position of lesser importance. It seems safe to say that no part of the academic community places greater stress on liberal education than do present-day scientists and mathematicians.

GUIDELINE I

Teacher education programs should provide experiences that foster continuous growth in those human qualities of the teacher that will enhance learning by his students.

A. *A teacher should show sensitivity to students.*

Sensitivity is a quality learned by interacting with others. It includes an ability to identify with others. This is not merely superficially "liking" students, but rather a personal involvement and a concern for their growth as human beings. Teacher education can contribute to development of the sensitivity of the prospective teacher by providing him with an atmosphere of compassion and concern in which to learn. A teacher or prospective teacher who has the qualities of sensitivity essential for effective teaching should:

"Interest, individualism and integrity cannot be mass-produced; they result from the personal interactions of man with man."[4] A. M. Cartter

1. Have the disposition to take student judgments and suggestions seriously.
2. Be intellectually honest with himself and his students.
3. Strive to develop an atmosphere in the classroom conducive to spontaneity, creative thinking, and independent, self-directed learning.
4. Be able to foster an environment of trust in his classroom.
5. Be able to use various modes of instruction most suited to individual student needs, modifying the structure in order to develop student self-confidence and independence.
6. Understand himself as a model for the development of student attitudes and behaviors in informal as well as formal teaching-learning encounters.

"Trust Takes Time."[5]

B. *A teacher should have self-esteem and confidence.*

The prospective teacher should have the opportunity to develop a self-concept of himself as a teacher of science

"Mathematics has many humanistic aspects that are not recognized so well today as they were during its liberal arts years."[6]
R. L. Wilder

"Yeh, he'll tell you that you can do your thing. Then he comes over and tells you what your thing is."
A Student

and mathematics. Experience with independent study involving the planning and execution of investigations in some areas of science, mathematics, or curriculum will contribute to self-confidence. The prospective teacher should demonstrate his self-confidence in the following ways:

1. Have enthusiasm for his teaching field as well as for his students.
2. Set up a study around a question of his own asking in an area of his own interest.
3. Ask relevant questions within his disciplines and listen to, accept, and respond to questions and ideas of his students, colleagues, and laymen.
4. Respond to a discussion of an experiment or study by asking reasonable questions that demonstrate an understanding of the purpose, principles, and results of the work.
5. Accept and encourage the widest possible range of interests and activities in students of all levels of ability and background.
6. Assume many different roles in the teaching-learning environment, including those of group leader, group participant, resource person, listener, and experienced investigator.
7. Obtain resources, including community resources, and help his students learn to use them in student-designed studies.
8. Support and encourage students to set up laboratory or field investigations.

Growth toward these goals will take place best if the prospective teacher is aware of the competencies he is expected to achieve and if his learning experiences are consciously designed to enhance his personal development.

GUIDELINE II

Teacher education programs should provide teachers with the knowledge and experience to illustrate the cultural significance of science, to relate science and mathematics through technology to social conditions, and to apply the analytical methods of science in multidisciplinary approaches to studying and solving societal problems.

"There is a need to study the role of science and technology in our life today as one of the important aspects of modern citizenship."[7] Howard H. Cummings

Science, as a body of knowledge and as a process of rational thought, permeates the culture of our time. Man's political, economic, social, ethical, and moral systems are greatly influenced by scientific achievements and their application through technology. Because of the pace of science in generating new knowledge and ideas and of technology in generating new products and applications, society is in a state of accelerating change.

It is reasonable that a major purpose for teaching science and mathematics should be to help young people adjust to change and to develop the skill and rationality to cope with societal transformations of the future. The teacher of science or mathematics needs to be able to relate science and technology to social conditions, particularly as they affect the individual. Based on an understanding of the interrelationships among education, science, mathematics, technology, and society, a teacher of mathematics or science should be able to:

1. Explain the roles of science and technology in the development of contemporary culture and thought by:
   a. Comparing these roles in the preindustrial revolution era with their roles today.
   b. Providing examples of the influence of science and technology on society and on the quality of life of the individual.
   c. Discussing the possible role of science and technology in developing an understanding of a particular social problem and explaining why the problem may not be soluble by purely scientific or technological means.

"What does it do besides pollute the atmosphere?"

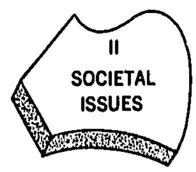
d. Identifying the major issues in the current dialogue about the responsibilities of scientists, mathematicians, and technologists for social problems.

2. Identify and apply analytical approaches and broad concepts of mathematics and science in the study of societal problems closely related to science and technology by:

   a. Exploring both the potentials and limitations of science for solving problems associated with man's welfare.
   b. Participating with his students in the design and implementation of activities that provide experiences in applied scientific decision-making.
   c. Developing appropriate techniques, such as optimization,[8] for making decisions.
   d. Learning how to relate feedback to the control of various systems, including social, political, economic, biological, physical, and technological systems.
   e. Extending concepts or definitions that may contain broader implications or applications than the context in which they are traditionally used. (Examples are half-life and entropy).
   f. Analyzing a problem in terms of more than one system, for example a localized system, a regional system, or a national or international system.
   g. Identifying the knowledge and methodology of the social sciences and law that might be necessary to attend to problems of broad social concern.
   h. Describing how science and technology might interact with economic, political, and social forces to influence the development of societies of the future.

The education of the teacher of secondary science or mathematics should require him to be conversant in several disciplines, including the social sciences, should provide learning opportunities that teach for synthesis among several disciplines and major areas of study, and should provide for a multidisciplinary perspective that will assist him in developing learning experiences for his students in science, technology, and society.

Because of his increasing responsibilities in developing public understanding of science and for sharing in the study of environmental and social problems, the prospective teacher will need to be something of a generalist rather than purely a specialist. The teacher needs to recognize what it is in science and mathematics that has value for the layman, with less consideration of what has value for the research scientist. It is conceivable that in the future the secondary school teacher will serve as an important intermediary between science and society, explaining science to the citizen and providing the feedback to scientists that will help them develop and maintain their sense of social responsibility.



"Man's most human characteristic, one which distinguishes him from other species . . . is [his] ability to teach . . . and to teach again."[9] J. Lawrence Walkup

III
NATURE OF
SCIENCE AND
MATHEMATICS

GUIDELINE III

Teacher education programs should provide opportunities for prospective teachers to gain insight into the intellectual and philosophical nature of science and mathematics.

As an interpreter of science or mathematics as an intellectually satisfying enterprise, a teacher must be comfortable with the history of his subject, its philosophical nature, its conceptual structure, and its investigative methodologies. Because each of the several disciplines taught in secondary schools differs in its validity requirements, permissible uncertainties, research strategies, and philosophical foundations, it is desirable that prospective teachers be knowledgeable about more than one discipline. The prospective teacher should be aware of the broader questions and concepts that arise from the differences and similarities among disciplines. Some typical generalizations are suggested below as examples.

1. Many characteristics of scientific and mathematical inquiry and interpretation are common to other human activities involving collation and abstraction. On the other hand, some characteristics are unique, such as the role of experimentation in science and the role of axiomatics in mathematics.
2. Nature is so diverse, complex, and vast that the study of science is open-ended.
3. A hierarchy of abstraction exists in mathematics and science covering a broad conceptual range from esoteric theories to engineering applications.
4. Achievements in mathematics and science are the results of human creative activity: the derivation of a mathematical theorem or the discovery of a scientific phenomenon provides an aesthetic appeal that is analogous to the appreciation of a work of art.
5. Human value judgments are influential in determining which aspects of science and mathe-

matics are of greatest interest and how those aspects are to be investigated. The collection and interpretation of data sometimes lead to disputes which arise when data are meager or when new and apparently inconsistent data are obtained allowing conflicting interpretations.

The generalizations described above are examples of the broader characteristics of science. Teacher education programs should translate these generalizations into more specific implications for the teaching of science or mathematics and should develop some standards by which the prospective teacher might gauge his progress. As examples, it might be expected that the prospective science or mathematics teacher be able to:

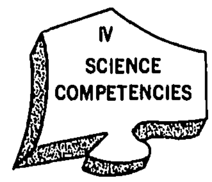
1. Demonstrate a knowledge of the methodologies, logical procedures, and explanatory systems that characterize the *natural sciences.*
   a. Compare the kinds of questions a biologist and a physicist would ask about a natural process such as photosynthesis.
   b. Contrast the kind of explanation that a physicist and an earth scientist would give for some phenomenon, such as a thunderstorm.
   c. Discuss explanations labeled as theories by physicists, chemists, biologists, and earth scientists and identify their similarities and differences.
2. Demonstrate a knowledge of the methodologies, logical procedures, and explanatory systems that characterize *mathematics* and compare or contrast them with the methodologies, procedures, and explanations in the natural sciences.
3. Compare scientific or mathematical "truth" with other kinds of "truths" that mankind has formulated.
   a. Describe the nature of evidence in the biological and theological accounts of evolution.
   b. Compare the nature of evidence in astrological and astronomical interpretations of a phenomenon.
   c. Contrast the scientific progress characterized by the development of classical and quantum mechanics with "cultural" progress characterized by the development of classical and modern art or music.

" . . . mathematics, contrary to popular belief, is not an absolute science but one which allows considerable arbitrariness in its content . . . It therefore affords an excellent opportunity for student participation in course content."[10] R. L. Wilder

III
NATURE OF SCIENCE AND MATHEMATICS

4. Trace a scientific or mathematical idea in terms of its origins, evolution, and absorption into the structure of a discipline; for example, identify critical periods in the history of the concept of atomic structure.
5. Show the power of a model for organizing thought about known phenomena; for examples, the algorithm in mathematics, evolution in biology, the expanding universe in astronomy, and the kinetic molecular model in chemistry and physics.
6. Show how scientific or mathematical ideas play a role in shaping a person's view of himself in the world. This might be exemplified by the contrast between an earth-centered cosmos and an expanding universe, the contrast between evolutionary development and special creation, or the contrast of mathematics as absolute truth and mathematics as a logical system dependent upon axioms and undefined terms.

GUIDELINE IV



The teacher education program should require the prospective science teacher to attain broad minimum competencies in several fields of science and technology and high levels of competence in an appropriate teaching specialty.

Teacher education programs should be responsive to the changing curricula of the secondary schools and to the changing role of the teacher. Secondary school science curriculum development projects of the past decade updated the materials and modified the teaching approach to include much more experimentation by students, but left largely unchanged the separation among the disciplines. There is currently beginning a movement to fuse the disciplines by emphasizing the common principles, concepts and processes and by teaching science in interdisciplinary or multidisciplinary contexts that are problem oriented. It may be not only desirable but necessary in the future to fuse the disciplines further and present the sciences within a broad context of humanism that includes personal characteristics of students as well as the more global concerns of mankind.

The changing nature of science education requires a broad base of experience stressing the interrelatedness of major concepts within the various disciplines and interpreting content and technological developments in terms of the needs of the individual and of society. Because science teachers will continue to perform a variety of functions, they must have sufficient breadth and depth to be effective in both general and specialized science education.

A. The teacher should attain at least minimum specified levels of competency in the processes of science common to the several disciplines.

All teachers of science need to have a specified minimum level of competence in using the processes of science that form the basis of the scientific search for knowledge and understanding. As examples of the competencies at this basic level, the prospective teacher should:

1. Be familiar with the basic elements of experimental design. He should be able to formulate a question as a testable hypothesis, describe observations that would support or refute the hypothesis, plan an investigation that would provide the appropriate observations with attention to the identification, control, and measurement of variables of the system.
2. Make use of models in science and mathematics. He should be able to identify essential elements of a model, describe the assumptions and the range of validity of the model, distinguish among competing models, identify the most appropriate model for a particular problem, and modify a model to accommodate new phenomena and observations.
3. Know how to measure a variety of quantities. He should be able to use the metric system of measurement and should know the relationship of metric units to other commonly used units. He should possess the manipulative skills and knowledge to use the ordinary instruments common to several fields.
4. Have the ability to plan for, make, and record observations. He should be able to make observations and measurements in a well-organized fashion and arrange a record of the data in a clear and orderly form.
5. Have a wide range of experience in interpreting data. He should be able to determine whether or not data are consistent with proposed models and whether or not they support or refute a hypothesis being tested. He should have in his repertoire of skills the ability to make graphical, analytical, and qualitative interpretations of data, to identify sources of error, and to make reasonable estimations of the accuracy, precision, and reliability of a given set of measurements. He should be able to examine data and to suggest additional kinds of observations or improvements in experimental techniques.

B. *The teacher should attain at least minimum specified levels of competency in the concepts and principles in several areas of science.*

To be able to function effectively in settings which relate a variety of previously isolated science disciplines or which confront the societal problems associated with but not necessarily attributable to technological developments, the prospective teacher needs to have at least minimum levels of competence in dealing with the major concepts of each of several traditional natural science disciplines. To identify a list of fundamental concepts of science that should be a part of the experience of every prospective science teacher is a hazardous undertaking because the selection is strongly influenced by individual value judgments and because the mere listing of topics gives no clue about the depth of understanding that is expected. Table 1 presents a *sample* range of topics that might be included as part of the training of all prospective science teachers and these are expanded in Appendix B. To demonstrate a broad level of understanding of the scientific enterprise, the prospective teacher should:

1. Have the ability to discuss qualitatively the fundamental concepts and significant experiments of science and their interrelationships. For each of the topics listed in Table 1, he should be able to describe at least two important ideas, illustrate the thought and experimentation leading to those ideas, and describe a widely accepted relationship between those ideas and each of the other topics.
2. Be able to interpret at least one significant question currently being addressed by researchers in each topic listed in Table 1.
3. Have an understanding of the relative magnitudes of the quantities observed or measured in the various disciplines and of the reliability of measurements required for information to be useful.
4. Be able to demonstrate that scientific principles and concepts belong to science in general and not necessarily to a particular subject area by giving examples of ways in which the ideas or instrumentation developed in one field find application in other fields.

TABLE 1

TOPICS OF SCIENCE AND TECHNOLOGY

- Physical and Chemical Interactions
  - mass, force, motion
  - gravitational, electrical, and magnetic fields
  - atomic and molecular interactions
- Energy
  - physical, chemical, and biological systems
  - thermal energy, radiation and entropy
- Atoms and Molecules
  - structure and models of atoms and molecules
  - subatomic particles
  - wave-particle duality
- Cosmological and Astronomical Models
- Earth Systems
  - oceanic, atmospheric, geophysical, geochemical
- Earth History and Evolution
  - biological and physical
- Inheritance—Genetics—Reproduction—Development
- Cell Theory
- Structure—Function—Homeostasis
- Organism—Environment—Interaction—Behavior
- Modeling and Prediction
  - computer simulation—programming
  - optimization
- Control of Systems
  - feedback
  - stability
- Interaction of Society and Technology

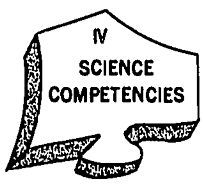
C. *The prospective science teacher should attain a specified high level of competence in a specialized field in order to be prepared to teach in that field.*

The appropriate preparation of secondary school teachers of physics, chemistry, biology, or other traditional disciplines is usually described by specifying a required minimum number of courses or credits. An academic minor is usually acceptable for certification, but a major is often required or strongly recommended. Rather than to assume that the completion of an array of courses and credits successfully equips the prospective teacher with the appropriate competencies for the teaching of science in the secondary school, the faculties of the individual institutions should carefully identify and define the subject matter competencies that are essential.

The broad faculty, school, and community representation required for the development of teacher education programs will provide the expertise and judgment necessary for acceptable formulation of meaningful competencies for the teaching of the discipline. Identical experiences for both the prospective teacher and the prospective research scientist may not be possible nor desirable. Guidelines that may assist the development of such competencies or courses of study are being, or have been, developed by several professional societies.[11]

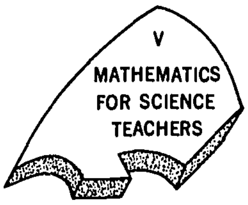
The types of competencies consistent with this guideline and suggestive for adaptation for specific disciplines are listed below. At this higher level of competency in a particular specialized field the teacher should be able to:

1. Explain and interrelate in considerable detail specified fundamental models, concepts, principles, and experiments of the field.
2. Describe the historical developments of significant concepts in the discipline and the relationship of these developments to society, to technology, and to scientific thought generally.
3. Analyze specified problems or systems quantitatively and apply the principles of the field to discover solutions.
4. Design and conduct original experiments that develop knowledge that is new or at least new for the student.
5. Use complex measuring techniques and procedures with units, equipment, and standards appropriate to the field.
6. Process and interpret data using a broad range of techniques and instrumentation characteristic of the field, including appropriate computer applications.



These suggested statements should be expanded and adapted to particular fields by specifying the details and the criteria by which the competence of prospective teachers should be judged.

GUIDELINE V



Teacher education programs should equip the science teacher with at least minimal mathematical competencies.

In view of the mathematical needs of high school students of science and the ever-increasing use of mathematics in science, it is essential that all science teachers have as minimal mathematical competencies the equivalent of those developed in two years of high school algebra, including elementary trigonometry. In addition, it is desirable that the prospective teacher of science have an acquaintance with the basic principles of differential and integral calculus, some knowledge of probability and statistics, and a brief introduction to computer programming. The prospective teacher should have:

1. The competency to perform simple algebraic manipulations and to use basic algebra and trigonometry to express relationships among physical quantities.
2. Sufficient knowledge of permutations, combinations, probability, and statistics to understand their use in specific areas of the sciences he is preparing to teach.
3. An understanding of those aspects of the calculus that will enhance the in-depth presentations of functional relationships involving time, motion, growth, forces, etc.
4. Sufficient knowledge of one of the simpler computer languages, such as Basic or Fortran, to be able to develop a program for the processing of data resulting from science experiments of limited sophistication.

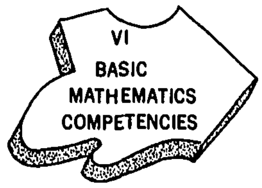
The effectiveness of any mathematics course for the prospective science teacher will be enhanced by attention to appropriate applications of mathematics to science and technology. However, the spirit in which mathematics is taught is as important as the extent and kinds of applications considered. The basic goal of mathematical preparation for the science teacher should be to make mathematics

V MATHEMATICS FOR SCIENCE TEACHERS

a functional tool. If this objective is achieved, the science teacher will turn naturally to whatever mathematics he knows to help him to guide his students to formulate and to explain scientific phenomena.

It will be helpful also for the science teacher to have some familiarity with the nature and method of modern school mathematics so that he can communicate more easily with mathematics teachers in correlating science and mathematics programs and so that he may be more helpful to his students who may not be accustomed to viewing mathematics as a functional tool.

GUIDELINE VI



An undergraduate program for secondary school mathematics teachers should include a major in mathematics of sufficient depth to make possible further study of mathematics at the graduate level in areas appropriate for teachers.

The professional preparation outlined here includes more than it may ordinarily be possible to arrange for in an undergraduate program. The prospective teacher's program of study should include basic studies in analysis, algebra, geometry, probability and statistics, and computing, and should permit further study at the graduate level to provide greater depth in these and other areas.

The design of the undergraduate major should provide the type of mathematical maturity which would permit graduate study in areas appropriate for teachers. Institutions offering graduate work in mathematics should make special efforts to provide studies relevant to mathematical background needed for secondary school teaching, and these studies should provide the teacher, as graduate student, with an open-ended approach which will foster continuous self-education.

The mathematical preparation which is believed to accomplish the objectives of Guideline VI is briefly described in the following pages. For more detailed descriptions, the reader is referred to the recommendations of the Panel on Teacher Training of the Committee on the Undergraduate Program in Mathematics.[13]

"Mathematics is a multistage Roman candle. It is packed with physical gunpowder and set alight by the fire of human minds. . . . Then the candle flares up and successive flashes of light reveal aspects of the physical world not readily illuminated from man's earthbound station."[12]
Morris Kline

A. ANALYSIS

The field of analysis (i.e., calculus and that part of mathematics which has developed from the calculus) must have a prominent place in the preparation of all secondary school mathematics teachers.

Every prospective high school teacher of mathematics should study elementary and intermediate calculus. He should:

VI BASIC MATHEMATICS COMPETENCIES

1. Be able to solve standard problems involving the differentiation and integration of elementary functions, and applications of these processes.
2. Be familiar with the extension of the processes of differentiation and integration to functions of more than one variable; he should understand the calculus of vector functions and be able to apply it to motion problems.
3. Understand the meaning of the implicit function theorem.
4. Understand the basic limiting processes as they occur in calculus, including infinite series, improper integrals, interchange of limits, and uniform convergence.
5. Be able to solve elementary differential equations and problems involving applications of first and second order differential equations.

In addition to the elementary and intermediate analysis discussed above, the prospective teacher of secondary school mathematics should have studied analysis at a more advanced level. He should:

1. Have worked through at least one of the several constructions of the real number system from the rationals.
2. Be familiar with the concepts of open set, limit point, closed set, and connected sets in the context of either the real line or (better) the plane.
3. Understand what it means for a function to be Riemann integrable, and know the conditions for integrability.

A teacher who is to be qualified to teach college level calculus (such as the Advanced Placement course) will need an especially thorough understanding of the topics above. He will also need to acquire greater depth in analysis by advanced study of several subjects, such as complex variables, measure and integration, and theory of differential equations. It may be that the necessary depth in analysis cannot be achieved in the prospective teacher's undergraduate program, and he should consult with his faculty advisor as to what study in his overall program should receive first priority and what should be deferred for later graduate study.

B. ALGEBRA

The prospective teacher should understand the elements of linear algebra. He should be acquainted with n-dimensional Euclidean spaces, and with the geometry and algebra of vectors in these spaces. He should know how to solve systems of linear equations, and should understand the uses of matrices in this connection. The future teacher will need to develop an understanding of the concept of a linear transformation, including its representation by a matrix, and he should be able to interpret his work in solving systems of equations in terms of linear transformations.

The student preparing to teach secondary mathematics should study the principal structures of abstract algebra, including groups, rings, fields, and vector spaces. For each of these structures he should see numerous elementary examples, both to give substance to the abstract ideas and to illustrate the power of mathematical abstraction. Rings should be illustrated through sets of integers, polynomials, and matrices; fields through the rational, real, and complex number systems. The group concept can be well illustrated through various groups of transformations, permutations, and symmetries. Such examples also offer an opportunity to point out interconnections between algebra and geometry.

The prospective teacher should understand the basic concepts of homomorphism, kernel, and quotient construction as well as applications and consequences of these ideas.

C. GEOMETRY

Informal and intuitive approaches to geometry are used in junior high school and in general mathematics classes. Even in deductive courses in geometry, informal explanations of relations among plane and space figures provide a basis for conjectures. Geometry is taught using a wide variety of approaches, including coordinates, vectors, and transformations such as isometries, similarities, and affine transformations. A teacher of geometry needs to be able to adapt his teaching to each of these approaches while maintaining flexibility to adapt to new approaches as future geometry courses continue to evolve. Accordingly, a prospective secondary school mathematics teacher should:

1. Be able to develop many of the usual geometric concepts informally; for example, using paper folding.
2. Know the role of axiomatics in synthetic geometry and the existence of various axiom systems for Euclidean geometry.
3. Be able to use either coordinates or vectors to prove theorems such as the concurrence of the medians of a triangle.
4. Recognize the existence of other geometries by being able to identify a few theorems in at least one other geometry such as a non-Euclidean geometry, projective geometry, or affine geometry.
5. Be able to discuss the role of transformations, at least in Euclidean geometry.
6. Understand thoroughly the interconnections between algebra and geometry.

Prospective teachers of geometry have a special need for understanding logic, particularly the fundamental principles used in mathematical reasoning. He should be familiar with connectives and the algebra of statements, various forms of the statements of implications and equivalences, and know how to express the denial of a statement involving universal or existential quantifiers.

D. PROBABILITY AND STATISTICS

Topics in probability and statistics are steadily finding their way into the curriculum of secondary schools. These are areas in which misconceptions frequently occur. Hence, it is particularly important that the prospective secondary school mathematics teacher be properly prepared to teach these subject areas. In the area of probability such preparation should include a careful presentation of the concepts of sample space (space of outcomes), event space, probability function, and the basic probability axioms. The development of the subject should cover additional probability through Bayes theorem and the basic concepts associated with random variables (distribution function, probability density function, expected value, mean variance, and standard deviation). The teacher should study calculus-based probability and statistics even though he would not teach probability and statistics at the secondary level from this point of view.

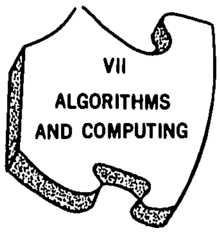
Statistics may be presented as applied probability in which probability space is used to model a situation in the real world. The associated concepts of statistical population, population parameter, and statistical sample should be emphasized. The development of the subject should include the ideas of statistical estimation, test of a statistical hypothesis, and confidence interval.

A teacher of probability and statistics should go beyond an understanding of the basic probabilistic concepts by having experiences using statistical analysis. He should have field and laboratory-type experiences in using probability concepts. In simple experimental situations, he should have the ability to collect the relevant data, prepare statistical summaries, select suitable methods of statistical analysis, and make the appropriate statistical computations.

E. OTHER MATHEMATICAL SUBJECTS

There is considerable variation in what students present as an undergraduate major in mathematics. The fraction of the total undergraduate program devoted to mathematics might be as little as a fourth, or as much as a half. A prospective secondary school teacher of mathematics should study a wider range of subjects than students with other goals, yet he must achieve in some areas a depth close to that of the prospective specialist. The demands of a liberal mathematical education and those of full professional preparation, always in conflict, are most severely so for the prospective teacher. He should plan, therefore, for more than a minimal major and should allow for study of subjects such as number theory, the history of mathematics or foundations, combinatorics, complex analysis, topology, as well as other disciplines in which mathematics is used. A graduate program in mathematics for prospective teachers should enable them to acquire breadth in mathematics as well as depth in a branch of mathematics such as algebra or analysis.

"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."[14]
David Ausubel



GUIDELINE VII

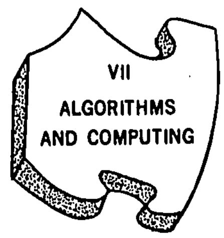
An undergraduate program for secondary school mathematics teachers should include a substantial experience with the field of computing as it relates to mathematics and to the teaching of mathematics.

The modern computer has already had a powerful effect on mathematics. An overhwelming majority of college-bound mathematics students (and many others) will eventually work with computers to some extent. The prospective teacher of mathematics should have an opportunity to develop an appreciation of the influence of the computer on the teaching of mathematics. The prospective mathematics teacher should:

1. Understand the relationship of mathematics to computing.
2. Have some appreciation of the effect computing has had, not only on the natural sciences but also on the social sciences, and on society in general.
3. Become familiar with the use of computers for individualized instruction and classroom demonstrations.
4. Recognize the limits of complexity of the general purpose computer.

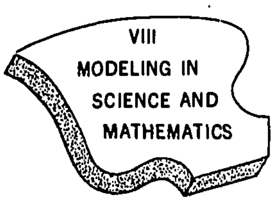
An important aspect of the computer revolution for mathematics education has been a renewal of interest in algorithms. There are a number of important topics in elementary mathematics where algorithms arise naturally; for example, approximating roots of equations, solving systems of equations, calculating the greatest common divisor of two integers, and evaluating lower and upper sums for the area under a curve. An "algorithmic" approach to the teaching of mathematics is now developing, and has many adherents; this movement seems very likely to gain in significance in the near future.

The prospective teacher might attain the necessary competence in computing through an independent study project, informal seminars, or formal study. Regardless of how he acquires his computer competency, the prospective teacher should be able to convert a physical model or problem to an algorithm; convert an algorithm to a flow chart; and convert a flow chart to a program in a language such as BASIC, FORTRAN, or ALGOL.



He should understand the following:

1. Computing systems: compilers, libraries, loaders, system programs, operation systems.
2. Program errors, debugging, and verification.
3. Data representation: systems of enumeration, binary codes, representation of characters, fixed and floating-point numbers, data structures.
4. Computation of errors and efficiency.



GUIDELINE VIII

An undergraduate program for secondary school mathematics teachers should provide substantial experience with mathematical model building so that future teachers will be able to recognize and construct models illustrating applications of mathematics.

"Certainly the lesson history teaches, and the reason for the great emphasis placed on mathematics today, is that mathematics provides the supreme plan for the understanding and mastery of nature."[15] Morris Kline

Applications of mathematics have traditionally been included in high school and college mathematics curricula through occasional exercises and minor digressions from the main development of mathematical ideas. Typically, a description of a highly artificial "real world" situation leads directly to a routine application of a formula that has just been studied (as in the so-called "word" problems), or a problem presented in mathematical terms is followed by a tenuous declaration that it arises in connection with a certain scientific study.

Students must be convinced that mathematics has a wealth of significant applications in many fields if they are to acquire a feeling of relevance about the study of mathematics. This can and should be done for college-bound high school students; it must be done for college students preparing to teach high school mathematics.

Aside from the obvious need for greater diversity and less artificiality in the applications that are included in mathematics study, there is a need for some specific study of mathematical model building to provide a frame of reference within which specific applications can be examined, constructed, and used.

"It is crucial that mathematics problems which claim to be applications of mathematics to other disciplines be *honest* applied mathematics."[16] Henry O. Pollak

In the sciences, most of the uses of mathematics, including equations and graphs, are examples of mathematics modeling. A mathematical model pairs elements of a mathematical system with practical and applied interpretations. Deductive operations in the model yield theorems which may then serve to predict or describe real events. For example, the symmetries that arise in our conceptions of nature, as in crystallography or quantum field theory, are treated as elements of mathematical groups.

The idea of a mathematical model of a "real" situation and the associated techniques and rationale of the model building process have developed as a sort of folk knowledge among mathematicians and users of mathematics during the past three or four decades. Only in recent years has there been any effort to make these ideas more explicit and to incorporate them in mathematics curricula. As these efforts begin to affect the high school curriculum, where much of the material belongs, it becomes urgent that the future high school teacher receive appropriate preparation. In turn, the preparation of teachers in these ideas will accelerate the desired implementation of the improved treatment of applications in the high schools.

The ideas of model building are conveyed best by developing examples in considerable detail, number, and variety. Consider, as a simple illustration, the problem of navigating from point A to point B on the surface of the earth. The approach to this problem depends on the distance between A and B, the precision with which the locations of A and B are known, and the accuracy required in the navigation. It is seen at once that the earth could be modeled by a plane, a sphere, or an oblate spheroid and that the choice of a model depends on the circumstances of the problem. Thus the role of simplifying assumptions in the process begins to be revealed: "We will assume that the earth is flat." Similarly, the connection between such assumptions and the complexity of the mathematical methods one must use (e.g., plane trigonometry or spherical trigonometry), as well as the available computational resources (hand computation, tables, a digital computer), soon becomes evident. There is little doubt that a thorough discussion of several such problems could be incorporated in the high school curriculum to good advantage. The prospective teacher should also work on problems more elaborate than this simple example. The models and the applications must be studied together as one part of the mathematics program at the senior level or distributed throughout the mathematical experiences of several years. It is recommended that students become actively involved in the construction and evaluation of models and that lecturing be minimized.

Because the concepts of mathematical model building are relatively new, a number of the features of the preparation in model building that teachers will need in order to teach applications of mathematics effectively are indicated in Table 2.

TABLE 2

ASPECTS OF MODEL BUILDING COMPETENCIES DESIRABLE FOR MATHEMATICS TEACHERS

Concerning Construction of the Model

- Illustrate the role of simplifying assumptions.
- Illustrate the role of accuracy requirements.
- Illustrate the role of computational resources.
- Illustrate the role of resources of mathematical knowledge.
- Illustrate the role of resources of knowledge in the field of application; in particular, the place of basic laws such as conservation laws and minimum principles.
- Demonstrate the logic of the model building process; in particular that a model can be put together by rough and ready methods (*ad hoc* assumptions, guess work, etc.) and that only in testing its validity do careful mathematical procedures need to be followed.
- Illustrate the trade-off between the realism of a model and its manageability.
- Discuss modifications of simple models to make them more realistic or more general.
- Discuss continuous versus discrete models of the same phenomena.
- Discuss deterministic versus probabilistic models.

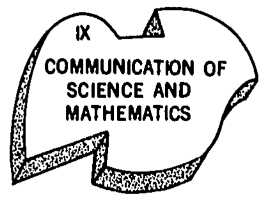
Concerning Testing of the Model

- Show how models are tested by drawing inferences about the situation that was modeled to compare with actual observations.
- Illustrate how a model often yields important information about the phenomenon that would otherwise be difficult or impossible to obtain.
- Show how a model can often be used to predict phenomena other than those it was explicity built to explain.
- Discuss the role of existence and uniqueness theorems in testing models.

VIII MODELING IN SCIENCE AND MATHEMATICS

Several illustrations of the kinds of competencies outlined in Table 2 are given in Appendix C.

Suitable materials for studying model building are scattered in various texts. In particular, some texts on "finite mathematics" and some calculus texts include good examples. There are excellent examples at the elementary level to be found in the textbook, *Manmade World*,[17] of the Engineering Concepts Curriculum Project (ECCP) and at an intermediate level in *Applications of Undergraduate Mathematics in Engineering*.[18] A limited edition of a collection, *Applications of Mathematics for Secondary School Teachers*,[19] is highly appropriate.



GUIDELINE IX

The teacher education program should provide the prospective science or mathematics teacher with experiences which require him to seek out and study concepts which are new to him, and then to synthesize written and especially oral expositions of them designed for others for whom these ideas are also new.

"All education worthy of the name enhances the individual."[20] John W. Gardner

Reading and talking science or mathematics are special skills which receive too little attention in undergraduate programs. Continuing substantial experience in "two-way" communication of scientific or mathematical ideas should be planned jointly by the faculties of teacher education institutions, secondary school personnel and future teachers. These experiences in reading, synthesizing, presenting, listening, and discussing with listeners can be planned as a part of the program—especially as a part of the study of the history and foundations of science or mathematics. In addition, they can be carried on through seminars, honors programs requiring oral and written reports, and club activities. These devices teach communication skills implicitly while also teaching science or mathematics. While traditional methods courses may include some activities of this type through search and analysis of the literature pertaining to the curriculum and pedagogy, the entire responsibility for training in scientific or mathematical communication should be left neither to methods courses nor to chance.

Examples of experiences in communication are listed below. The prospective science or mathematics teachers should prepare and present to an audience:

1. The solution of a problem such as those that appear in professional journals or books of contest problems.

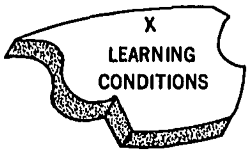
Mathematics	*Science*
American Mathematical Monthly	*Scientific American*
	The Physics Teacher
School Science and Mathematics	*New Scientist*
	The Biology Teacher

2. An exposition of a concept or a topic which is not a part of the usual secondary school or undergraduate curriculum.

Mathematics	*Science*
continued fractions	strange particles
curves of constant breadth	superconductivity
congruences	weather control
Gaussian integers	ratio astronomy
(See New Mathematics Library enrichment booklets; NCTM 28th Yearbook)	genetic engineering fusion power induced mutations

3. A description and analysis of an application from a scientific discipline, showing the source of the problem, explaining its importance, describing the construction of a model, and detailing the processes of solution and interpretation.
4. A discussion of the historical development of a major theme, giving some idea of prerequisite concepts, the problems and motives leading to its development and the theories and applications flowing from it.

Mathematics	*Science*
irrational numbers	atomic theory
complex numbers	kinetic theory
concept of a function	heredity and natural selection
mapping	relativity
transformation	quantum physics
	physical optics
	microbes and cells



GUIDELINE X

Teacher education programs should provide experiences that will enable the prospective teacher to learn about the nature of learning, conditions that help young people learn, and how to maintain a proper learning environment.

"The human skills, appreciations, and reasonings in all of their great variety, as well as human hopes, aspirations, attitudes, and values, are generally recognized to depend for their development largely on events called learning."[21] Robert M. Gagné

The most important challenge for the teacher is to facilitate learning. Even the best qualified teacher candidates have much to learn about learning, as do all practicing teachers, and indeed as do all who write guidelines for teacher preparation programs. Although much is known about learning and the learning environment, much more needs to be known; and it is fortunate for education that research in learning is currently one of the most active fields of scientific study.

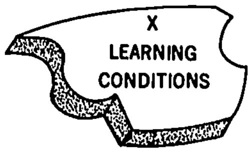
Teachers need to be familiar with what research says about learning. They need to observe many different learning situations and to put into practice what they have learned about learning by working with individuals, with small groups, and with large classes of young people. They should have experiences with classroom situations commonly found in American schools, and with innovative learning environments about which so much is now written in educational journals and the public press. Teacher education programs should also provide experiences in which the prospective teacher associates with students in both school and community activities, so that he will learn more about young people and how they learn, outside as well as inside the classroom.

Secondary school teachers of science and mathematics should be able to:

"[These] difficulties in identifying the content of learning would be avoided if care were taken to put the emphasis where it belongs, which is on the attainment of learners."[22] Robert M. Gagné

1. Describe the nature of the physical, emotional, and intellectual development of secondary school students.
2. Exchange ideas about adolescent development with peers, professors, and with those in the community who are interested in the schools.
3. Describe the behavior of secondary school students, both as individuals and as members of group.

4. Report what research says about learning and demonstrate how the research can be applied in the teaching of science or mathematics.
5. Analyze structure and processes in science or mathematics and develop plans to accommodate individual learning styles of students to facilitate their understanding of structure and processes in science or mathematics.
6. Plan teaching experiences so that the classroom becomes a laboratory—a relevant learning environment that fosters questioning and exploration and that develops in the students the disposition and ability to use what they know to learn more.



XI
MATERIALS
AND STRATEGIES

GUIDELINE XI

Teacher education programs should develop the ability of the future teacher to select, adapt, evaluate and use strategies and materials for the teaching of science or mathematics so that teaching-learning situations for which he is responsible will be consistent with general knowledge about teaching and learning and will be appropriate both to the special needs of the learners and to the special characteristics of the science disciplines or the interdisciplinary problem.

"Some of the major disasters of mankind have been produced by the narrowness of men with a good methodology . . . . To set limits to speculation is treason to the future."[23] Alfred North Whitehead

It is important that teacher education programs provide the prospective teacher with opportunities to learn to use the special methods and techniques characteristic of science and mathematics education. The organization and supervision of student projects and research, equipment selection and maintenance, and the conduct of field work are examples of skills related to teaching science and mathematics that the future teacher should be prepared to use.

The prospective teacher needs to have an opportunity to study teaching and learning theory and classroom management techniques as they relate specifically to the teaching of mathematics and science. Generalized consideration of such matters as guidance, testing and evaluation, psychology, social and philosophical foundations of education, and curriculum are valuable; but students should have experience with these concepts in the context of teaching mathematics, physics, chemistry, biology, earth science, or unified science.

In his preservice preparation he should have many opportunities to observe good teacher models—teachers who are effective in stimulating and developing creative inquiry, careful investigative skills, and enthusiastic interest among students with different backgrounds, abilities, and goals. He should observe and discuss a variety of individual styles for planning and guiding laboratory experiences, leading discussions, lecturing, advising, and engaging students in tutorial instructional dialogues.

XI MATERIALS AND STRATEGIES

The prospective teacher should have experience in working with many different kinds of students representing different cultural backgrounds and levels of ability. In his preparation the future teacher should have many opportunities to observe others teach, to practice teach with a variety of students, and to develop the skill to adapt his teaching of science and mathematics to high- or low-achieving students, whatever the cause of their disadvantage or advantage and whatever the range of their aptitudes.

"... no aspiring young professional should be forced into a situation where he is warped to fit somebody else's preconceptions."[24] Fred T. Wilhelms

Education in the inner city poses special problems. Years of discrimination and oppression of the minority groups who live there have resulted in environments and life styles that are severely restricted in motivating influences, cultural support for learning, and opportunities for scholarship. Student problems that are a direct result of these social and environmental factors can be dealt with effectively only by the most imaginative, energetic teachers with special training above and beyond that of the normal level. It may be assumed that students most in need of help will not appreciate or accept the usual teaching efforts. The teacher of students with learning disadvantages, whether caused by situations of health, environment, poverty, social conditions, cultural discontinuities or bad teaching, must have at his command abundant resources— in humane interpersonal qualities, in teaching materials, in cultural understanding, in mathematical and scientific background, and in personal commitment.

A teacher education program should specify concisely and comprehensively its plan for developing the skills to use the methods and materials of good science teaching. The sample list of experiences and outcomes given here is intended to serve only as a model.

1. Given a description of a group of students and a specific science or mathematics content area, the prospective teacher will be able to:
   a. develop a set of behavioral expectations for those students;
   b. devise at least two instructional strategies to achieve those objectives;
   c. carry out one of the strategies according to plan;
   d. monitor the level of performance of the students; and

XI MATERIALS AND STRATEGIES

e. evaluate the successes and failures of the plan and its implementation in accordance with acceptable criteria.

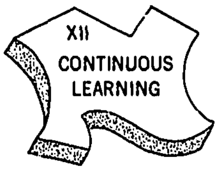
2. The prospective teacher will be able to develop and apply a set of rational criteria to guide him in the selection and use of a variety of media for the purpose of helping students achieve specified objectives. He should:
   a. be able to make critical comparisons and judgments about various secondary school science and mathematics programs;
   b. know the sources of readily available media and materials for science and mathematics instruction; and
   c. be able to develop instructional materials and strategies through such channels as programmed instruction or audio-tutorial instruction.
3. The prospective teacher will be able to devise evaluation systems to monitor and measure change and development of student behaviors in specified areas such as knowledge, level of achievement, problem-solving skills, or inquiry skills within specified science or mathematics content areas. The prospective teacher should have experience with a variety of approaches to evaluating changes in pupil behavior that incorporate sound principles of behavioral measurement techniques and describe levels of achievement in terms of established competency levels.
4. The prospective teacher will be able to develop and refine criteria he may use to evaluate his own instructional strategies and performance and will be able to adapt his teaching performance in accordance with his evaluation. He will be able and willing to use audio- and/or video-tape recordings of his teaching to evaluate the congruence between his teaching objectives and his actual teaching performance—between the learning objectives and the learning outcomes.

"A problem well put is half solved."[25] John Dewey

5. The prospective teacher will be able to select a general goal of education and describe in concrete terms how mathematics or science education can contribute to the attainment of that

goal. He will be able to plan, conduct, and evaluate educational experiences in science or mathematics to help secondary students achieve the qualities or abilities described in the general goal.

XI
MATERIALS
AND STRATEGIES



GUIDELINE XII

An undergraduate program for secondary school mathematics and science teachers should develop the capacity and the disposition for continued learning in mathematics and science and the teaching of these subjects.

"Now that we're students.... I can feel a wave of revolutionary dissent already."

Developing the habit of continued study and learning—both formal and informal—is possibly the most important single task of teacher preparation programs. Without this habit, the teacher will lose intellectual vitality, his teaching is likely to become dull and ineffective, he will have difficulty in coping with future changes in education, and he will quickly become obsolete. With the habit of continued study and learning, he can steadily enrich his knowledge of mathematics and science, and deepen his understanding of the subjects, thereby improving his teaching skill and effectiveness.

In their undergraduate years students should become convinced that learning mathematics and science independently is exciting and rewarding. They should come to a full recognition that studying and keeping abreast of new developments in their field, new applications, and new pedagogy, must be a lifetime professional commitment for teachers. Throughout their careers teachers must continue to develop toward a higher, more creative level of learning and teaching. As they acquire more scientific knowledge and wider teaching experience, they must constantly strive to present scientific concepts more creatively and to interpret their relation to societal structure more sensitively. In these ways they will demonstrate growth as scientists, as teachers, and as individuals.

In the preservice teacher education program a variety of devices can be used to contribute to the achievement of these long-term goals.

Some possibilities are for the teacher education program to provide opportunities for the prospective teacher to:

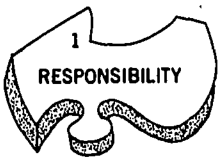
1. participate actively in communication of science and mathematics as required in Guideline IX;

XII CONTINUOUS LEARNING

2. complete a major in mathematics or science that will prepare him for graduate study in mathematics or science appropriate for teachers, as proposed in Guideline VI for mathematics;
3. conduct or investigate on his own scientific experiments or mathematical problems new to him;
4. associate with a faculty which by its vigorous interest in continued study and investigation sets an example for students to emulate;
5. study and discuss with faculty and fellow students new curricular or teaching materials;
6. participate in curriculum design (elementary, secondary, or college);
7. participate in teaching or tutoring in experimental programs or programs using new materials or new audio-visual aids;
8. maintain continued counseling with faculty and share with them in a regular reevaluation of his own program; and
9. assess and articulate his own professional and intellectual growth.

It is recommended also that future teachers be encouraged to become student members of such professional organizations as the National Council of Teachers of Mathematics, National Science Teachers Association, Mathematical Association of America, National Association of Biology Teachers, American Association of Physics Teachers, or the American Chemical Society.

Teacher education should be viewed in the framework of continuous learning, self-evaluation, and self-renewal beginning when a student first considers becoming a teacher and continuing throughout his career. Guidelines Conference



STANDARD 1

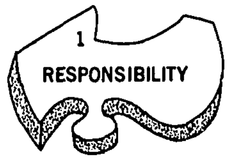
In planning, preparing, and carrying out teacher education and accreditation programs, teacher education institutions and state departments of education should seek the advice and participation of all groups interested in the schools.

Effective science and mathematics teacher education is an enterprise that requires the cooperative efforts of many individuals and groups—students, college faculties, school systems, state departments of education, scientific societies, professional teacher organizations, local community groups, and industry. Too often in the past, the many resources essential for truly effective teacher education have not been marshaled by teacher education institutions and state departments of education.

Within the teacher education institution itself there should be cooperation among faculties of the various disciplines involved in educating teachers. Faculties of science, mathematics, education, psychology, sociology, and philosophy should coordinate their teaching as much as possible and should plan programs emphasizing interdisciplinary approaches. Institutions are also urged to involve students in planning and carrying out many parts of the teacher education program.

Between the colleges and school systems, cooperative arrangements should be made to draw on the resources of the institutions and their faculties at a variety of levels. There should be cooperation between colleges and schools in developing individualized teacher education programs, in providing future teachers with an opportunity to participate in many different kinds of activities in assessing teacher education programs as well as student progress. The identification, recruitment, selection, and retention of future teachers should be a cooperative enterprise between colleges and schools.

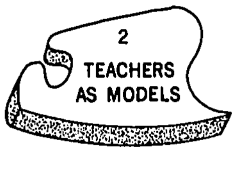
The diversity of talent available through *scientific societies* should be drawn on by colleges that are developing new science and mathematics teacher education programs or reassessing existing ones. The changing nature of science and mathematics makes the scientific societies particularly valuable in such cooperative endeavors.



Likewise, *professional teacher organizations* and *state departments of education* can contribute particular skills and viewpoints to the development of a teacher education program. Cooperation between colleges and state departments should give the departments information and knowledge about programs that will aid in the process of program approval. The wide experience of professional teacher organization and state department personnel with many colleges and with national teacher groups can be a major asset to the college in program planning and development.

Industries can provide resources and arrange visits that will contribute to the education of teachers by developing an awareness of the interrelationships among science, technology, and society.

Social agencies, community organizations and *recreational programs* can provide to teachers opportunities to work with young people outside the school environment and thereby to create in the teachers an awareness of nonschool factors in students' lives that may contribute directly to their learning outside the classroom or that may affect the learning process in the classroom.



STANDARD 2

Teacher education institutions should systematically recruit qualified faculty with diverse backgrounds and styles of inquiring, teaching, and living.

"What you are speaks so loudly kids cannot hear what you say."[26] Environmental Studies

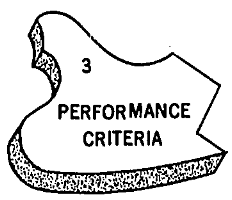
In this decade, teacher education can and must be a lively enterprise. As new goals and objectives of education are identified, new teaching aids are more widely used, new administrative structures are adopted in the schools, new emphases on content and process are introduced, and as completely new types of teacher education programs are tried, teacher education faculties will have greatly increased demands on their resourcefulness and time. As they are confronted with social issues of great future import, faculties will find their responsibilities as teacher educators increasingly more challenging and at the same time more satisfying. How they meet these challenges will determine in very great measure the kinds of teachers they send into the schools.

Teachers, consciously or unconsciously, use their own teachers as models as they develop their own styles of teaching, inquiring, and living. Because future teachers will and should represent a wide range of life-styles and teaching-styles, teacher education institutions are obligated to provide a wide range of models among those who teach prospective teachers. Each person contributing to the preparation of teachers should be aware that his style of inquiring, living, and teaching has a significant influence on future teachers.

In selection of teacher education faculties, vigorous interest in continued study and research is an important criterion. Consideration should also be given to the institution at which the prospective faculty member has been trained, the part of the country from which he comes, the nature of his teaching experiences, and his avocational interests, in order to ensure that a variety of backgrounds are represented on the total faculty. Teaching philosophies often differ from institution to institution, and teaching and living styles sometimes differ from one part of the country to another. Prospective teachers will recognize these differences among teacher education staff members and thus become aware of the variety of kinds of life- and teaching-styles from which they may choose.

The teacher education community is well aware that a multitude of research studies in which attempts to correlate personal characteristics of teachers with teaching success have lead to little that is certain. Just as every child is an individual, so is every teacher an individual. The future teacher experiences good and bad teaching at all levels and, from what he observes, he develops his own style according to what he believes will enable him to be most successful. Exposure to many styles of inquiring, teaching, and learning will greatly assist the future teacher in developing a style appropriate for him, as a teacher and a person.

2
TEACHERS AS MODELS



STANDARD 3

Teacher education institutions should develop performance criteria as guides in planning teacher education experiences, in evaluating teacher education programs, and in assessing the ability of prospective teachers to contribute to effective learning.

"When the outcomes of any learning event are described in terms of the performance such learning makes possible, it becomes apparent that the kinds of capabilities inferred deserve to be called *intellectual skills*."[27] Robert M. Gagné

Some of the skills and competencies that an effective teacher has can be described in performance terms. Each faculty member who teaches teachers should describe in as much detail as possible what he expects his students to be able to do upon the completion of the part of the preservice program for which he has a responsibility. The descriptions will include the knowledge and skills that a beginning teacher would be expected to have or to demonstrate.

The development and general use of a checklist of performance criteria for the total program should become a joint effort of the teacher education faculty, students, and cooperating school personnel. Furthermore, it is important that any checklist be continually revised and updated to respond to new understandings about learning and to reflect changes in education in the schools.

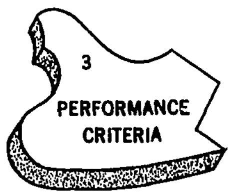
A checklist of performance criteria, cooperatively developed by all those concerned with the teacher education program, can serve many useful purposes, such as:

"Programs of teacher education may be evaluated at any one of three levels: . . . the program . . . the competence of the teachers . . . or . . . the learning of the children taught by these teachers . . . no program . . . is good unless it produces teachers who can contribute to effective learning."[28] Paul Woodring

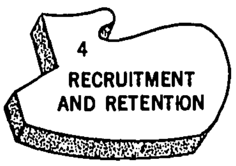
1. planning modifications of programs and introducing innovations;
2. assessing the effectiveness of the teacher education programs of individuals and groups;
3. counseling students before and after admission to teacher education programs;
4. assisting future teachers in determining their own successes and failures, in identifying competencies they need before entering teaching, and in assessing for themselves the likelihood that they will become happy and successful teachers;
5. recommending beginning teachers for certification on evidence of attainment of competencies described in the checklist; and

6. identifying problems for investigation and research.

Certification and accrediting agencies should urge teacher education institutions, where possible, to develop lists of performance criteria and to base their recommendations for certification on evidence of attainment of competencies described in these lists. Other information about future teachers should also be utilized in recommendations for certification, but evidence of acquisition of certain skills and competencies can be a source of important objective information.



"... we accept all kinds of shoddy education that is no more than going through the motions. We pretend that so many courses, so many credits, so many hours in a classroom, so many books read add up to an education."[29]
John W. Gardner



STANDARD 4

Teacher education institutions and cooperating agencies should establish systematic procedures for identifying, recruiting, and retaining teachers in the teaching profession.

Much progress has been made in the past decade by teacher education institutions in improvement of practices for selection and retention of students in undergraduate teacher education programs. To meet the needs of the decade of the seventies it is necessary not only to broaden the involvement to include students and school and lay people in selection and retention of teacher candidates, but equally important to extend the responsibility of teacher education institutions.

"That which is honored in a nation will flourish." Plato

Precollege Identification

Cooperation with schools in identification and selection of teacher candidates makes it possible to begin this process in high schools, including the junior high school years, when so many young people first choose careers. Teacher education institutions are urged to accept a responsibility for identifying and recruiting, during their precollege years, those young people demonstrating a potential for teaching, working in close cooperation with schools and community leaders. Quite a large number of schools are introducing high school students to the excitement of teaching through cadet programs in which secondary school students teach elementary school children, or assist high school science teachers in laboratories. These programs are to be encouraged and the teacher education institution should offer cooperation and consultant assistance to enhance their effectiveness.

The Undergraduate Years

The selection and retention procedures in the undergraduate years need to be strengthened. The involvement of students and school and lay people will contribute much. Identification and communication of goals of the undergraduate teacher education programs, as urged in Standard 3, will contribute to more objective evaluation of teacher education programs and student progress and thus be of valuable assistance in retaining those who show promise as teachers, and in redirecting to other fields those least qualified to teach. Encouraging and assisting better self-evaluation may be the most effective way of improving the selection and retention process.

Still another practice gaining widespread acceptance in teacher education is the individualization of programs of teacher candidates. Some students enter teacher education programs with many of the competencies and personal characteristics that the program is designed to develop. Others may require a full four-year program or even more to acquire these competencies or personal characteristics. Proper planning of individual programs in full cooperation with the student is a crucial step in guidance and retention. Too many good people have been lost to the teaching profession because they were required to go through programs which they did not need, and too many others have failed as teachers because they were not provided the experiences that could have helped them most.

Retention in the Profession

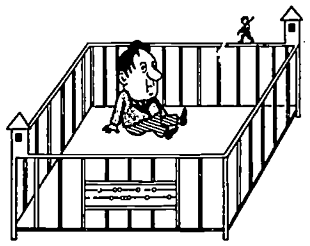
Just as teacher education institutions are improving their procedures for selection and retention, they are also strengthening their relationships with and service to teachers in their first few years of teaching. Much more needs to be done in cooperation with the employing schools and the communities in which the new teachers are acquiring their first experience. Visits of college faculty members to the schools of new teachers, conferences of the new teachers back on the campuses at which they had their preparation, and regular reporting to the institution by the schools all can be helpful.

Other ways in which the teacher education institution can assist in retaining competent teachers in the profession include:

1. Developing graduate-level programs which can accommodate the many interests and needs of teachers.
2. Working with professional organizations to persuade school systems to offer leaves with pay and rewards for periodic graduate-level study, work experience, or travel.
3. Working with professional organizations to develop professional attitudes on the part of teachers and the acceptance of professional responsibilities.

4. Establishing, in cooperation with communities and professional organizations, agencies to which teachers could go for consultation, career evaluation, and career development planning.

EPILOGUE



Variety in teacher preparation is not only inevitable, it is desirable and necessary; individuals should not be forced to fit into a single pattern of experiences in education, science, and mathematics. Provision must be made for personalized programs of study. New techniques for evaluation are needed. Most importantly, the teacher's preparation should foster an open and humane mind, and encourage versatility, motivation, and confidence for continuing pursuit of self-education and self-development.

It is the intent of this document to encourage a broadening of the competencies of the teacher and to place his preservice and inservice science education in a context which will encourage his deepening knowledge of science and mathematics and will foster independence and continued growth in the ability to help others learn. To this end, it is essential that college teachers engaged in teacher education possess and exhibit in their actions those qualities expected in the development of the future secondary school teacher.

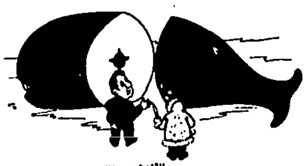
David Ost

APPENDIX A

IMPLEMENTATION

Guidelines which are read, briefly discussed, and then placed in a file or on a shelf are of no real value. The only criterion for judging the merit of the guidelines is the extent to which the various recommendations are implemented or are influential in stimulating change in teacher education programs.

The implementation of the guidelines will depend primarily upon the teacher education institutions, with encouragement and assistance from state and regional agencies. The following suggestions may be of assistance in efforts to implement the recommendations set forth in this document.



"Now what?"

a. *Colleges and universities preparing teachers should:*
    1. Arrange for discussions of the guidelines among college faculties and students, recent graduates, elementary and secondary school teachers, administrators, supervisors, and the community at large. Every opportunity should be taken to generate formal discussions of the guidelines.
    2. Encourage review of the guidelines by people in curricular areas other than science and mathematics. The guidelines should be useful in stimulating development of strategies, competencies, and general approaches for the improvement of teacher education in all areas.
    3. Compare the guidelines with state-adopted teacher preparation programs and standards to identify possible conflicts.
    4. Consider the utilization of the guidelines in the evaluation of collegiate programs which prepare teachers of science and mathematics for secondary schools.
    5. Utilize the guidelines to encourage inservice and continuing education experiences for teachers.
    6. Take appropriate action regarding the adoption of the guidelines.

b. *State education agencies should:*
    1. Promote widespread distribution and discussion of the guidelines.
    2. Utilize the guidelines to provide opportunities for dialogue among the communities of science,

mathematics, and education, and to develop action programs within the state, including models of operation.

3. Provide for presentation and discussion of the guidelines at meetings.
4. Sponsor special conferences for introduction and discussion of the guidelines.
5. Publicize the guidelines as well as reactions to it in their journals.
6. Consider the guidelines as a basis for the development of statements of teacher competencies and teacher self-evaluation instruments.

c. *Schools and school districts should:*

1. Consider the guidelines in developing criteria for screening teacher applicants.
2. Consider the guidelines in developing instruments and procedures for evaluating teacher competencies and prescribing professional growth activities.
3. Consider the teacher competencies proposed in the guidelines as a basis for planning inservice opportunities for teachers.

d. *Professional organizations at the national and state levels should:*

1. Distribute copies of the guidelines to their members who can make use of it.
2. Consider these guidelines in terms of existing guidelines developed by the individual associations.
3. Plan cooperative research and development projects so that departments of science, mathematics, and education become involved in defining competencies for science and mathematics teaching, consistent with the guidelines.
4. Develop procedures by which the achievement of competencies can be measured.
5. Encourage consideration and use of the recommendations by faculties responsible for community college and lower-division program development.
6. Encourage college teachers of science, mathematics, and education to study the guidelines, to evaluate their teaching with reference to the guidelines, and to modify their present practices as seems appropriate.

7. Prepare reports for presentation at professional meetings and for publication in professional journals describing how these guidelines and recommendations are being used.

e. *Funding agencies should consider the guidelines in evaluating proposals for funding of preservice and inservice training programs for secondary school science and mathematics teachers.*

APPENDIX B

UNIFIED SCIENCE MODEL AND RELATED SCIENCE TEACHER COMPETENCIES

The following model, together with its specified subject matter competencies, is presented as an *example* of a specific program for the broad preparation of science teachers. As designed by Carl Pfeiffer and the science teaching staff of Monona Grove High School, Monona, Wisconsin, the content of science is centered around the nature of matter and energy and interactions which, with the passage of time, result in change. These components of science constitute the frame of reference for the development and interpretation of knowledge in all science disciplines.

Various unifying themes associated with these components of science can be used to structure a model useful in establishing broad minimum levels of subject matter competency essential for all teachers of science. This particular model is based on the premise that understanding the nature of matter and energy provides the basis for understanding the interactions which are a part of the ongoing change within the environment. The emphasis is not only on the mechanism of change but also on the implications of change for the individual and for society.

Matter

Structure

The structure of matter, described in terms of its general properties, provides the basis for understanding *what* matter is. With reference to the general structure of matter, all teachers of science should have a basic understanding of:

1. the particulate nature of matter including fundamental ideas about atomic and molecular structure, the historical development of the atomic theory, and the kinetic molecular theory;
2. the structure of cells and modern cell theory;
3. the thermal and electrical properties of matter; and
4. the characteristics of elements, mixtures and compounds.

Special Properties

The special properties provide the basis for further understanding matter and for distinguishing one kind of matter from another. With reference to the special properties of matter, all teachers o, science should:

1. be familiar with the special structural characteristics of atoms, isotopes, ions, radicals, isomers, tissues, organs, systems, organisms, populations, community, ecosystem, biosphere, solar system, galaxy, and universe;
2. have some knowledge of the special properties of certain types of chemical compounds such as acids, bases, salts, carbohydrates, fats, proteins, nucleic acids, enzymes, and the characteristics of covalent and electrovalent compounds; and
3. have a working knowledge of such physical quantities as specific gravity, specific heat, heat of fusion and vaporization, atomic weights and numbers, molecular weight, equivalent weight, and oxidation numbers.

Occurrence and Classification

Knowledge about the occurrence and classification of matter provides the basis for understanding man's relationship to matter. All teachers of science should:

1. have some knowledge of the distribution of elements and minerals in the hydrosphere, geosphere, and atmosphere;
2. have a working knowledge of the periodic table of the elements;
3. understand the basis for distinguishing between metals and nonmetals, organic and inorganic compounds, living and nonliving matter, various types of rocks and minerals, soil types, and land forms; and
4. be familiar with the basic classification system for living things: protista, plants, and animals.

Energy

Transfer Mechanisms

Energy transfer mechanisms provide the basis for understanding how energy is transferred from one body to another and from one point in space to another. Teachers of science should be familiar with:

1. the mechanism for the transfer of mechanical energy via particle collisions, and mechanical waves;
2. the mechanism for thermal conduction, convection, and radiation;

3. the wave-particle nature of radiant energy;
4. the mechanisms for the flow of electrons between points differing in electrical potential; and
5. electron transfer and sharing associated with the formation and breaking of chemical bonds.

Transformation

Knowledge of the various energy forms and how one form of energy can be transformed to another provides for understanding how energy is controlled and used. With reference to energy transformation, all teachers of science should be familiar with:

1. the concepts of kinetic and potential energy;
2. the equivalence between mechanical, electrical and thermal energy;
3. the basic mechanism by which energy transformations occur;
   a. light (photon energy)↔ chemical bond energy,
   b. light (photon energy)↔electrical energy,
   c. mechanical energy↔thermal energy,
   d. mechanical energy↔electrical energy,
   e. thermal energy↔electrical energy,
   f. electrical energy↔chemical bond energy,
   g. nuclear bond energy↔mechanical, thermal and radiant energy;
4. methods for measuring the quantity of energy being transformed or used; and
5. the equivalence of matter and energy.

Resources

Knowledge of energy sources provides the basis for understanding energy reserves and man's dependence upon energy resources. All teachers of science should have some knowledge of:

1. naturally occurring energy resources such as the energy associated with the movement of air and water, the energy associated with the movement of matter in force fields, solar radiation, terrestrial heat, fossil fuels, and nuclear fuels; and
2. ways in which energy can be stored such as in naturally occurring processes or in man-made devices.

Change

Interactions

Interactions provide the basis for understanding natural phenomena. All teachers of science should have some understanding of the following basic interactions:

Mechanical

- Interactions associated with gravitational force fields.
- Molecular interactions associated with forces of cohesion and adhesion.
- Interactions resulting in distortion of bodies.
- Interactions which affect the physical equilibrium of bodies.
- Interactions associated with the particle kinetics of fluids and gases.

Electrical

- Interactions which affect the electrical neutrality of matter.
- Interactions associated with electrical force fields.
- Electromagnetic interactions.
- Interactions associated with the flow of electrons.

Magnetic

- The production of magnetic fields.
- Interactions associated with magnetic force fields.

Thermal

- Change of phase associated with the loss or gain of heat energy.
- Heat exchange mechanisms—1st law of thermodynamics.
- Entropy—2nd law of thermodynamics.

Radiant

- Interactions associated with absorption, reflection, refraction, and interference of radiant energy.
- Interactions associated with the propagation of electromagnetic energy.

Nuclear

- Interactions involving nuclear fission and fusion.
- Interactions associated with transmutation and radioactivity.

Biological

- Interactions associated with *function:*

  cell function; digestion; fermentation; respiration; replication of molecules, cells, and organisms; heredity; growth and development; and biogeochemical cylces.

- Interactions associated with *adaptation:*

  gene mutation, natural and artificial selection, population genetics, evolutionary changes, problems of coexistence, and behavior.

Interactions associated with *succession:*

population growth and control, evolution of species, ecological succession, and interactions between populations and the environment.

Chemical

Interactions involving different types of chemical reactions:

synthesis, decomposition, exchange, replacement, oxidation, reduction, dissociation, and ionization.

Interactions associated with the formation of chemical compounds:

ionic bonding, covalent bonding, activation energy, oxidation potentials.

Geological

Interactions associated with the geosphere:

water and wind erosion, glaciation, rock and soil formation, disastrophism, volcanism, and mountain building.

Interactions associated with the hydrosphere.

Interactions associated with the atmosphere:

climatic interactions.

Systems

A system is a portion of the environment, defined in space and time, which is isolated for the purpose of studying matter and interactions within and across the defined boundaries. The selection of particular systems as frames of reference for investigating various interactions is a matter of convenience and personal preference. However, all teachers of science should be familiar with:

1. the characteristics of static and dynamic systems;
2. ways and means of disturbing, controlling, and measuring the state of equilibrium within a system; and
3. various ways of "simulating" natural systems for the purpose of making qualitative and quantitative studies of interactions which cannot be conveniently isolated in their natural state.

Social Implications

The social implications of the various changes characteristic of nature provide the basis for understanding man and his relationship to the environment. All teachers of science should be able to interpret science in such a way that:

1. the science experience of the student has meaning at the personal level,
2. students understand how and why man is dependent upon his environment,
3. students are able to identify ways in which science and technology have affected society and ways in which society has affected science and technology,
4. students recognize the limitations of science and technology in terms of what they *can* and *cannot* do, and
5. the science experience of the student provides a rational basis for making value judgments about what science and technology *should* and *should not* do for the individual and society.

APPENDIX C

SELECTED EXAMPLES OF THE ASPECTS OF MODELS LISTED IN TABLE 2

Model: Exponential (or geometrical) growth in time t of some quantity, $x = x_0 2^{t/A}$, where A is the time of doubling for the quantity and x_0 is its initial value at t = 0. The defining characteristic of the model is that at a given time the rate of increase of the quantity is proportional to the amount already present, i.e., $\frac{dx}{dt} = kx$.

Example: Increase of a bacterial population, of the number of people who have heard a rumor, or of the number of people who have contracted a highly contagious disease.

Simplifying Assumptions

Factors that materially inhibit growth have not yet appeared. The quantity x is treated as continuous when it is, in fact, discrete. In short, a model is chosen partly to simplify mathematical analysis or to make it possible.

Accuracy Requirements

For discrete x, the model is unrealistic when the total population is too small or when the time interval is so short that the increment in population is too small.

Computational Resources

By including inhibiting factors, the governing equation may be changed to an insoluble form, say $\frac{dx}{dt} = kx + f(x, t)$ but approximate solutions can be found.

Resources of Mathematical Knowledge

Anything known about the differential equation can be applied to all the samples of the model. Any general theory of differential equations or of computation of solutions can be brought to bear on this particular example.

Logic of the Model Building Process

A bacterial population increasing by cell division in a suitable nutrient bath should double in the average time between cell divisions.

More Realistic Models

A disease can spread only so long as a non-immune population remains. The logistic equation is $\frac{dx}{dt} = kx(x_1 - x)$, where x: represents the initial population available to contract the disease.

Deterministic vs. Probabilistic Models

In bacterial growth, replace the hypothesis that every cell takes the same time to subdivide with the idea that the probability of a single cell's subdivision in a specified time interval is all that is known.

APPENDIX D

THE JUNIOR HIGH SCHOOL TEACHER OF MATHEMATICS

In most states a teacher who holds a certificate to teach mathematics in secondary schools is approved for teaching in any of the grades 7 through 12. There is no separate certificate for teaching in junior high school or for teaching in senior high school. In quite a number of states a teacher who holds an elementary school certificate is approved to teach in grades 7 and 8. Particularly for this reason, and also because teacher education institutions sometimes offer special programs for the preparation of junior high school teachers of mathematics, two of the review conferences recommended strongly that a description of a minimum program for junior high school mathematics teachers be published with these guidelines. The program proposed by one of these conferences is presented below.

The preparation of the prospective junior high school mathematics teacher should include:[30]

1. *Elementary Calculus* to the extent of being able to solve standard problems involving the differentiation and integration of elementary functions and applications of these problems.
2. *Algebra* to the extent of understanding the elements of linear algebra, of demonstrating an ability to solve systems of linear equations (including solution through matrices), and grasping the concept of a linear transformation. The solution of linear equations through graphing should be applied, particularly to solving simple problems in linear programming. The prospective teacher should understand the structure of abstract algebra, especially rings and fields, through the study of numerous elementary examples, particularly those involved in the development of the number system.
3. *Geometry* to the extent of recognizing and understanding the role of proof without undue emphasis on formal proof. Many examples of intuitive approaches to geometric concepts should be explored and exploited.
4. *Probability and Statistics* at least to the extent of experiencing laboratory activities and field

work as suggested for senior high school. Such a study should be designed to exclude the calculus prerequisites.

5. *Number Theory,* at least to the extent of understanding the various aspects of prime numbers, even and odd numbers, perfect numbers, and triangular numbers.
6. *Historical Topics in Mathematics,* at least to the extent of those appropriate to the content of junior high school mathematics.

APPENDIX E

A MODEL FOR TEACHER CANDIDATE EVALUATION

The model suggested here is but one possible way in which teacher candidate capabilities and growth can be assessed. Alternative methods should be developed by teacher education institutions in the context of their programs.

At the earliest possible stage of the prospective teacher's education he is invited to rate himself. A 10-point scale checklist or other instrument might be used.[31] The student's advisors, in consultation with those college teachers who have dealt with him during a given term or year, assist the student in determining his qualifications. Judgment of many of the qualities requires the views of peers and secondary school students. Each prospective teacher is asked to solicit rating sheets from both classmates and high school students before each conference with his advisors. The peer-rating process in which each candidate evaluates his colleagues can be an important aspect in the development of competence in self-evaluation.

The student and advisors, in conference with other faculty members as necessary, discuss the results of the assessment and develop plans for improvement. These evaluation and advising conferences are exceedingly important. Each prospective teacher, after his initial commitment to a career of teaching, has two or more such conferences during each semester of his education. The conferences include representatives of several areas involved in teacher education and are more than simple evaluation or advising sessions. They are essential learning experiences. Self-evaluation techniques must be learned; mutual trust between advisor and advisee must be developed. Clearly, advisors must have close personal contact with the advisee and know him well as a person.

The individual as a human being must be paramount in all phases of the evaluation—in the recruitment phase, the preservice program and the secondary school classroom. The development and evaluation process proposed in this model is humanistic. Although rating sheets are used in making a growth profile for the prospective teacher, one must be cautious not to reduce the teacher to a series of numbers, for this would lose sight of the very human being that should emerge from a teacher education program.

A prospective teacher is considered eligible for certification when he and his advisor agree that he has reached an appropriate level of competency as a teacher.

The notion of continuing education is a valid one and should be based on all preceding experiences. Periodic reevaluations and comparisons with earlier evaluations should become a part of a permanent record and thereby contribute to life-long self-evaluation and continuing education. In each instance, separate rating sheets should be prepared by the teacher himself, his students, his administrators, and colleagues. The assembled ratings should provide a basis for discussion between the teacher and his colleagues or administrators.

Every teacher should know what kind of teacher he is, what kind of teacher he wants to be, and also *what he must do* to become the kind of teacher he wants to be. Consequently, teacher education must ensure that each teacher recognizes a responsibility for self-evaluation and continued growth in those human qualities which favor learning by his students.

APPENDIX F

PROJECT PARTICIPANTS

Alphabetical Listing

**denotes committee members*
***denotes Advisory Board members*

Adams, Albert, Chief, Bureau of Teacher Education, Certification, and Accreditation, Florida State Department of Education, Tallahassee
***Albritton, Claude,** Department of Geology, Southern Methodist University, Dallas, Texas
Alder, Henry L., Department of Mathematics, University of California, Davis
Allen, Frank B., Chairman, Department of Mathematics, Elmhurst College, Elmhurst, Illinois
Andersen, Hans O., School of Education, Indiana University, Bloomington
Anderson, James G., Department of Chemistry, University of Portland, Portland, Oregon
Armstrong, Terry, Department of Education, University of Idaho, Moscow
Awkerman, Gary, Director of Natural Sciences, Charleston County School District, Charleston, South Carolina
Beard, Jean, Department of Natural Science, San Jose State College, San Jose, California
Begle, Edward G., School of Education, Stanford University, Stanford, California
Bell, Max, Graduate School of Education, University of Chicago, Chicago, Illinois
Bell, Paul E., Department of Science Education, The Pennsylvania State University, University Park
Bellisario, Joseph L., Secondary Supervisor, Tredyffrin/Easttown School District, Berwyn, Pennsylvania
Benson, Bernard W., Department of Education, University of Tennessee, Chattanooga
Bents, Ulrich H., Department of Physics and Earth Sciences, California State Polytechnic College, Pomona
Berkey, Gordon B., Department of Physics, Minot State College, Minot, North Dakota
Biesecker, Carl E., Consultant for Mathematics, Science, and Conservation Education, Arizona State Department of Education, Phoenix
Bingham, N. E., Department of Science Education, University of Florida, Gainesville
Bixby, Louis W., Chairman, Science Department, St. Louis Country Day School, St. Louis, Missouri
Blakeway, Edward G., Needham B. Broughton High School, Raleigh, North Carolina
Blank, Albert A., Department of Mathematics, Carnegie-Mellon University, Pittsburgh, Pennsylvania
Blessing, Leonard C., Science Department Head, Milburn Senior High, Milburn, New Jersey
Bordogna, Joseph, The Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia
Borst, Kenneth E., Department of Chemistry, Rhode Island College, Providence
Bradford, John, Mathematics Supervisor, Jefferson County System, Denver, Colorado
Bray, Edmund C., Committee on Secondary Education in Physics, Minneapolis, Minnesota
Brennan, John W., Department of Instructional Services, Denver Public Schools, Denver, Colorado
Bridgham, Robert G., School of Education, Stanford University, Stanford, California
Brieske, Phillip R., Director, Center for the Advancement of Science Education, Wisconsin State University, Superior
Briggs, John W., Mathematics Consultant, Idaho State Department of Education, Boise
Brooks, A. Gordon, Director of Teacher Education, Virginia State Department of Education, Richmond
***Brown, John A.,** Departments of Education and Mathematics, University of Delaware, Newark
Brown, Stanley B., Department of Science Education, California State Polytechnic College, San Luis Obispo
Browne, Kenneth A., Consultant in Teacher Education, Maryland State Department of Education, Baltimore
Brumbaugh, Joe H., Department of Biology, Sonoma State College, Rohnert Park, California
***Burkman, Ernest,** Department of Science Education, Florida State University, Tallahassee
Burnett, Keith R., Department of Secondary Education, Weber State College, Ogden, Utah
Butler, John E., Department of Biology, Humboldt State College, Arcata, California
Campbell, J. A., Department of Chemistry, Harvey Mudd College, Claremont, California
Carry, Ray L., Departments of Mathematics and Education, University of Texas, Austin
Carter, Jack L., Department of Biology, Colorado College, Colorado Springs
****Charlesworth, William L.,** Director, Bureau of Teacher Education, Pennsylvania State Department of Education, Harrisburg
Choppin, Gregory R., Chairman, Department of Chemistry, Florida State University, Tallahassee
Clark, Richard C., Science Consultant, Minnesota State Department of Education, Saint Paul
Coash, John R., Dean, School of Natural Science and Mathematics, California State College, Bakersfield
Cole, Llewellyn, Supervisor of Secondary Science, Kanawha County Schools, Charleston, West Virginia
Cole, Mildred B., University of Maryland Mathematics Project, University of Maryland, College Park
***Colvin, Burton H.,** Head, Mathematics Research Laboratories, Boeing Scientific Research Laboratories, Seattle, Washington
Conlon, Betsy, Intermediate Science Curriculum Study, Florida State University, Tallahassee
Connelly, Lucille J., Director of Science, Chicago Public Schools, Chicago, Illinois
Contee, Carl, American Federation of Teachers, Washington, D.C.
Correll, Malcolm, Department of Physics, University of Colorado, Boulder
***Cossman, George W.,** Department of Science Education, University of Iowa, Iowa City
Cram, S. Winston, Department of Physics, Kansas State Teachers College, Emporia
Crider, Russell J., Supervisor of Teacher Education and Certification, Mississippi State Department of Education, Jackson
Cummins, Kenneth, Department of Mathematics, Kent State University, Kent, Ohio
Curry, Richard, Department of Mathematics Education, Southwest Minnesota State College, Marshall
Curtis, K. Fred, Administrative Consultant in Science and Mathematics, Nebraska State Department of Education, Lincoln
Dalton, Leroy C., Chairman, Mathematics Department, Wauwatosa West High School, Wauwatosa, Wisconsin
D'Arcy, Harold M., Department of Chemistry, Southern Connecticut State College, New Haven
Dasbach, Joseph M., Staff Associate, American Association for the Advancement of Science, Washington, D.C.
***Davis, Charles,** Curriculum Specialist, Fairfax County Public Schools, Fairfax, Virginia
Davis, Kenneth E., Department of Physics, Reed College, Portland, Oregon
Deady, Gene M., Department of Science Education, Chico State College, Chico, California
Dean, Donald S., Chairman, Department of Biology, Baldwin-Wallace College, Berea, Ohio
***DeRose, James,** Marple-Newtown Schools, Newtown Square, Pennsylvania
Dessart, Donald J., Departments of Mathematics and Mathematics Education, University of Tennessee, Knoxville
Dieter, Donn L., Assistant Executive Secretary, National Association of Biology Teachers, Washington, D.C.
DiLavore, Philip, Associate Chairman, Department of Physics and Astronomy, University of Maryland, College Park
***Dilworth, Robert P.,** Department of Mathematics, California Institute of Technology, Pasadena
Dittmer, Karl, Division of Science, Portland State University, Portland, Oregon
Dixon, Peggy A., Department of Physics, Montgomery College, Takoma Park, Maryland
Domanowski, David, Assistant Superintendent and Coordinator of Transcript Evaluation, State Teacher Certification Board, Springfield, Illinois
***Drummond, William,** Teacher Education and Certification, Washington State Department of Education, Olympia
***Dubisch, Roy,** Department of Mathematics, University of Washington, Seattle
Durst, Harold, Department of Biology, Kansas State Teachers College, Emporia
Edwards, Judith, Research and Development Specialist, Northwest Regional Educational Laboratory, Portland, Oregon
Eiss, Albert F., Associate Executive Secretary, National Science Teachers Association, Washington, D.C.
Estee, Charles R., Chairman, Department of Chemistry, University of South Dakota, Vermillion
Estin, Robert W., Chairman, Department of Physics, Roosevelt University, Chicago, Illinois
Evans, Rudolph, Forestville High School, Chicago, Illinois
Evans, Thomas P., Department of Science Education, Oregon State University, Corvallis

Farmer, John D., Consultant in Science Education, North Carolina Department of Public Instruction, Raleigh
Farnum, Bruce W., Department of Chemistry, Minot State College, Minot, North Dakota
Feaster, William H., Chairman, Department of Natural Sciences, Castleton State College, Castleton, Vermont
Felton, James (student), University of Chicago, Chicago, Illinois
*Ferguson, W. Eugene, Head, Mathematics Department, Newton High School, Newtonville, Massachusetts
*Fiasca, Michael, School of Education, Portland State University, Portland, Oregon
Fisch, Forest N., Department of Mathematics, Colorado State College, Greeley
Finigan, Francis X., President, National Science Supervisors Association, and Director of Science, Winchester Public Schools, Winchester, Massachusetts
Fitzpatrick, David, Assistant Director, Bureau of Teacher Certification, Massachusetts State Department of Education, Boston
Foncannon, Howard F., Associate Director of Education, American Association for the Advancement of Science, Washington, D.C.
Frank, Andrew J., Department of Chemistry, Western Washington State College, Bellingham
**Freeman, J. P., Director, Division of Teacher Education and Certification, North Carolina State Department of Public Instruction, Raleigh
Frisinger, Howard, Department of Mathematics and Statistics, Colorado State University, Fort Collins
Gallagher, James Joseph, College of Environmental and Applied Science, Governors State University, Park Forest, Illinois
Gardner, Marjorie, Science Teaching Center, University of Maryland, College Park
Garner, James, Supervisor of Science Programs, State Department of Education, Olympia, Washington
Garth, R. E., Department of Biology, University of Tennessee at Chattanooga
Gawley, Irwin H., Dean, School of Mathematics and Science, Montclair State College, Upper Montclair, New Jersey
Gierl, Erika, Department of Education, Marquette University, Milwaukee, Wisconsin
Goodwin, Betty (student), University of Chicago, Chicago, Illinois
Gottlieb, Herbert H., Martin Van Buren High School, Queens Village, New York
Grambs, Jean Dresden, Department of Secondary Education, University of Maryland, College Park
Greene, Alan C., Staff Physicist, Commission on College Physics, University of Maryland, College Park
Greene, Paul, Director of Teacher Education and Certification, Missouri State Department of Education, Jefferson City
Griffing, Leo R., Elementary and Secondary Accreditation Section, Kansas State Department of Education, Topeka
Grigsby, Clifford E., Director, Division of Teacher Education and Certification, Indiana State Department of Public Instruction, Indianapolis
Gross, Phyllis P., Department of Biological Sciences, California State College, Hayward
Haber-Schaim, Uri, Director, Physical Science Group, Education Development Center, Newton, Massachusetts
*Haenisch, Edward, Department of Chemistry, Wabash College, Crawfordsville, Indiana
Hailey, Paul W., Director, Teacher Education and Certification, Ohio State Department of Education, Columbus
Hale, Helen, Coordinator, Office of Science, Board of Education of Baltimore County, Towson, Maryland
Halfar, Edwin, Department of Mathematics, University of Nebraska, Lincoln
Hall, Lucien T., Jr., Supervisor of Mathematics, Richmond Public Schools, Richmond, Virginia
Hanson, Robert W., Department of Chemistry, University of Northern Iowa, Cedar Falls
Hardgrove, Clarence E., Department of Mathematics, Northern Illinois University, DeKalb
Harris, Jesse M., Science Consultant, Dallas Independent School District, Dallas, Texas
Haygood, Neal T., Chemistry Department, Wakefield High School, Arlington, Virginia
Heinke, Clarence H., Department of Mathematics, Capitol University, Columbus, Ohio
Henderson, George L., Supervisor of Mathematics Education, Wisconsin Department of Public Instruction, Madison
Herron, J. Dudley, Department of Chemistry, Purdue University, Lafayette, Indiana
Hess, Adrien, Department of Mathematics, Montana State University, Bozeman
*Hestenes, Magnus, Department of Mathematics, University of California, Los Angeles
Hiebert, Vern, Department of Mathematics, Oregon College of Education, Monmouth

Hillam, K. L., Department of Mathematics, Brigham Young University, Provo, Utah
Hilzman, John, Department of Mathematics, Idaho State University, Pocatello
Hodges, Thomas F., Assistant Director of Teacher Education and Certification, Oklahoma State Department of Education, Oklahoma City
Hoeksema, Paul D., Department of Science Education, School of Teacher Education, Ferris State College, Big Rapids, Michigan
Hoff, Darrel, Department of Science Education, University of Northern Iowa, Cedar Falls
Hoff, William E., Chairman, Department of Mathematics, Concord College, Athens, West Virginia
Holden, Stanley J., Coordinator of Scientific Research, Wilkes College, Wilkes-Barre, Pennsylvania
Holland, F. D., Jr., Director, Council on Education in the Geological Sciences, and Director of Education, American Geological Institute, Washington, D.C.
Hoskins, Thomas (student), University of Chicago, Chicago, Illinois
Howe, Robert W., Chairman, Faculty of Science and Mathematics Education, Ohio State University, Columbus
*Huff, Warren D., Department of Geology, University of Cincinnati, Cincinnati, Ohio
*Hughes, Barnabas B., School of Education, San Fernando Valley State College, Northridge, California
Hull, George, Jr., Chairman, Department of Biology, Fisk University, Nashville, Tennessee
*Hurd, Paul DeHart, School of Education, Stanford University, Stanford, California
Irby, Bobby N., Chairman, Department of Science Education, University of Southern Mississippi, Hattiesburg
Ireton, Leroy F., Mathematics and Science Specialist, Oklahoma State Department of Education, Oklahoma City
Irving, James R., Science Education Consultant, Stoughton, Wisconsin
Ivany, J. W. George, Department of Science Education, Teachers College, Columbia University, New York, New York
Jackson, Stanley B., Department of Mathematics, University of Maryland, College Park
*Jacobson, Willard, J., Chairman, Department of Natural Sciences, Teachers College, Columbia University, New York, New York
James, Robert K., College of Education, Kansas State University, Manhattan
Jerkins, Kenneth F., Professor and Chairman, Department of Science Education, Morgan State College, Baltimore, Maryland
Johnson, Randall M., Chairman, Department of Biology, Kennedy-King College, Chicago, Illinois
Johnson, Robert L., Department of Mathematics, University of Northern Colorado, Greeley
Johnson, Wilbur, American Association of Physics Teachers, Washington, D.C.
Jones, Burton W., Department of Mathematics, University of Colorado, Boulder
Jones, Jack E., Superintendent, Bonner County School District No. 82, Sandpoint, Idaho
*Jones, Phillip S., Department of Mathematics, University of Michigan, Ann Arbor
Kay, Richard, State Science Consultant, Idaho State Department of Education, Boise
*Keiffer, Mildred, Administrative Supervisor of Secondary School Mathametics, Cincinnati Public Schools, Cincinnati, Ohio
Kennedy, Manert H., Associate Director, BSCS, University of Colorado, Boulder
Kessel, William G., Department of Chemistry, Indiana State University, Terre Haute
*King, L. Carroll, Department of Chemistry, Northwestern University, Evanston, Illinois
Kirk, Harvey C., Department of Zoology, Santa Monica College, Santa Monica, California
Knapp, John W. (student), Western Michigan University, Kalamazoo
Kochendorfer, Leonard, Department of Education, Valparaiso University, Valparaiso, Indiana
Kormondy, Edward J., Director, Commission on Undergraduate Education in the Biological Sciences, Washington, D.C.
*Kowal, Norman, Department of Biology, West Virginia University, Morgantown
Kreider, Donald L., Department of Mathematics, Dartmouth College, Hanover, New Hampshire
Lacey, Archie L., Department of Education, Herbert H. Lehman College, City University of New York, Bronx, New York
Landin, Joseph, Department of Mathematics, University of Illinois at Chicago Circle, Chicago
Lange, L. H., Dean, School of Natural Sciences and Mathematics, San Jose State College, San Jose, California

Latham, James W., Jr., Consultant in Science, Maryland State Department of Education, Baltimore
Lawrence, Otis O., Director of Curriculum, Board of Education, Oklahoma City, Oklahoma
Lay, L. Clark, Department of Mathematics, California State College, Fullerton
**Lee, Addison E., Director, Science Education Center, The University of Texas at Austin
Lightner, Jerry P., Executive Secretary, National Association of Biology Teachers, Washington, D.C.
Lindquist, Albert A., Department of Education, California State College at Los Angeles
**Livermore, Arthur H., Deputy Director of Education, American Association for the Advancement of Science, Washington, D.C.
Lloyd, Elizabeth C., Director of Teacher Education and Professional Standards, Delaware State Department of Public Instruction, Dover
Lockard, J. David, Departments of Secondary Education and Botany, Science Teaching Center, University of Maryland, College Park
Long, Calvin T., Department of Mathematics, University of Oregon, Eugene
LoPresti, Peter L., Chief, Bureau of Teacher Preparation and Certification, Connecticut State Department of Education, Hartford
MacMahon, Miles D., Director, Natural and Applied Science, Essex County College, Newark, New Jersey
Maier, Eugene, Department of Mathematics, University of Oregon, Eugene
Maler, George J., Dean, College of Engineering, University of Colorado, Boulder
Mallinson, Jacqueline V., The Graduate College, Western Michigan University, Kalamazoo
Masla, John A., Teacher Corps Director, State University College at Buffalo, Buffalo, New York
Mattheis, Floyd E., Chairman, Department of Science Education, East Carolina, University, Greenville, South Carolina
Mayfield, Melburn R., Director, The Center for Teachers, Austin Peay State University, Clarksville, Tennessee
*Mayer, William V., Director, Biological Sciences Curriculum Study, Boulder, Colorado
**Mayor, John R., Director of Education, American Association for the Advancement of Science, Washington, D.C.
McAda, Harleen W., Graduate School of Education, University of California, Santa Barbara
McCamman, Carol V., Managing Editor, National Council of Teachers of Mathematics, Washington, D.C.
McGinnis, Thomas J., Jr., Director of Teacher Certification, West Virginia State Department of Education, Charleston
McGuire, Donald C., Program Director, Pre-Service Teacher Education Program, National Science Foundation, Washington, D.C.
McNeary, James J., E.C.C.P. Coordinator, College of Engineering, University of Wisconsin, Madison
Merrill, Richard J., Consultant in Secondary Curriculum, Mount Diablo Unified School District, Concord, California
Meserve, Bruce E., Department of Mathematics, University of Vermont, Burlington
*Mierzwa, Sigmund (student), Stanford University, Stanford, California
Miller, J. David, School of Education, University of California, Berkeley
Miller, Sister May Ivo, Educational Division, Fischer Scientific Company, Chicago, Illinois
Miller, Wilfred H., Science Coordinator, Alfred I. duPont School District, Wilimington, Delaware
Mills, Grant J., Coordinator of Teacher Certification, Oregon Board of Education, Salem
Mock, Gordon D., Department of Mathematics, Western Illinois University, Macomb
Morin, J. Wilfred, Director, Bureau of Professional Services, Maine State Department of Education, Augusta
Morris, Victor D., Department of Science Education, Indiana University Northwest, Gary
*Nearhoof, Orrin, Director of Teacher Education, Iowa Department of Public Instruction, Des Moines
Nessman, Paul, Hubbard High School, Chicago, Illinois
Netzel, Richard G., Assistant Academic Vice President, Wisconsin State University, Oshkosh, and Acting Deputy Director of Education, AAAS
Newton, David E., Department of Chemistry and Physics, Salem State College, Salem, Massachusetts
Novak, Alfred, Chairman, Division of Science and Mathematics, Stephens College, Columbia, Missouri
Obradovich, Eli, Consultant in Teacher Education, California State Department of Education, Sacramento
Okey, James R., School of Education, Indiana University, Bloomington
*Olsen, Ingrith D., Department of Zoology, University of Washington, Seattle
Olstad, Roger G., College of Education, University of Washington, Seattle
Ortgiesen, Leroy, Assistant Commissioner, Division of Instructional Services, Nebraska State Department of Education, Lincoln
**Ost, David H., Coordinator, Teacher Education Project, American Association for the Advancement of Science
Pallrand, George J., Department of Education, Rutgers University, The State University of New Jersey, New Brunswick
Palmer, Elra M., Supervisor of Science, Baltimore City Public Schools, Baltimore, Maryland
Parker, Nathan (student), University of Chicago, Chicago, Illinois
Peak, Philip, School of Education, Indiana University, Bloomington
*Pedrick, George, Department of Mathematics, California State College, Hayward
Pella, Milton O., Department of Science Education, University of Wisconsin, Madison
Pestrong, Raymond, Department of Geology, San Francisco State College, San Francisco, California
Peterson, Richard S., Specialist, Science Education, Utah State Board of Education, Salt Lake City
Petrucci, Ralph H., Division of Natural Sciences, California State College, San Bernardino
Pfau, Ed, Director, Division of Teacher Education and Certification, Michigan Department of Education, Lansing
Pfeifer, Glenn L., Department of Mathematics, University of Arizona, Tucson
*Pfeiffer, Carl H., Science Department Coordinator, Monona Grove High School, Monona, Wisconsin
Phelps, C. Russell, Associate Director, Conference Board of the Mathematical Sciences, Washington, D.C.
Phillips, Melba, Department of Physics, University of Chicago, Chicago, Illinois
*Piel, E. J., Executive Director, Engineering Concepts Curriculum Project, Polytechnic Institute of Brooklyn, Brooklyn, New York
Pier, L. N., Director of Teacher Education and Certification, South Dakota Department of Public Instruction, Pierre
Pignani, Tullio J., Chairman, Department of Mathematics, East Carolina University, Greenville, North Carolina
Postl, A., Department of Natural Sciences and Mathematics, Oregon College of Education, Monmouth
*Pownall, Malcolm, Department of Mathematics, Colgate University, Hamilton, New York
Pratt, Charles, Head, Department of Physical Sciences, Alabama State University, Montgomery
Prowse, D. J., Department of Physics, University of Wyoming, Laramie
Puri, O. P., Chairman, Department of Physics, Clark College, Atlanta, Georgia
Rapp, George, Jr., Associate Chairman, Department of Geology and Geophysics, University of Minnesota, Minneapolis
Rathert, Harold, Supervisor of Science, Des Moines Public Schools, Des Moines, Iowa
Reed, Carl (student), University of Chicago, Chicago, Illinois
Rice, Dick C., Vice President, University of Maine at Farmington
Rissler, Rolla R., Director of Special Projects, Aurora Public Schools, Aurora, Colorado
Rituper, Stephen, Jr., Curriculum Coordinator, Bethlehem Area School District, Bethlehem, Pennsylvania
Robinson, James T., Biological Sciences Curriculum Study, Boulder, Colorado
*Romey, William D., Director, Earth Science Teacher Preparation Project, Boulder, Colorado
Roseberry, Dean A., Department of Biology, Northeast Missouri State College, Kirksville
Rucker, Isabelle P., Supervisor of Mathematics, Virginia State Department of Education, Richmond
Ruff, Otto G., Supervisor, Teacher Education and Certification, Colorado State Department of Education, Denver
Rusch, John J., School of Geology and Geophysics, University of Oklahoma, Norman
Samples, Robert E., Earth Science Teacher Preparation Project, Boulder, Colorado
Sandercock, Edward R., Visiting Associate Professor, Rensselaer Polytechnic Institute, Troy, New York
Sands, Richard H., Department of Physics, University of Michigan, Ann Arbor
Scandura, Joseph M., Graduate School of Education, University of Pennsylvania, Philadelphia
Schein, Martin W., Department of Biology, West Virginia University, Morgantown
Schmidt, Donald, Department of Biology, Fitchburg State College, Fitchburg, Massachusetts
Schneider, David, I., Department of Mathematics, University of Maryland, College Park

Schubert, Leo, Chairman, Department of Chemistry, The American University, Washington, D.C.

Schult, Veryl, Division of Elementary-Secondary Education Research, U.S. Office of Education, Washington, D.C.

Schulz, Charles E., New Trier Township High School East, Winnetka, Illinois

Scott, Leland Latham, Department of Mathematics, University of Louisville, Louisville, Kentucky

Settine, R. L., Department of Chemistry, University of Alabama in Birmingham

Shamos, Morris H., Department of Physics, New York University, New York, New York

Shrum, John W., Chairman, Department of Science Education, University of Georgia, Athens

***Simandle, Sidney,** Director, Division of Teacher Education and Certification, Kentucky State Department of Education, Frankfort

Sinclair, Ward, Associate Director, Office of Teacher Education and Certification, New Jersey State Department of Education, Trenton

Sindt, Vincent, Director, General Education Services, Wyoming State Department of Education, Cheyenne

***Smith, Frank W., Jr.,** Science Department, Los Altos High School, Los Altos, California

Smith, John P., College of Education, University of Washington, Seattle

Smith, Lucy L., Instructional Supervisor, Atlanta Public Schools, Atlanta, Georgia

Smith, W. Norman, Department of Mathematics, University of Wyoming, Laramie

Stegner, Robert W., Department of Biology and Education, University of Delaware, Newark

Stevens, John C., Department of Science Education, Southwest Minnesota State College, Marshall

Stoever, Edward C., Jr., School of Geology and Geophysics, University of Oklahoma, Norman

Strassenburg, Arnold A., Director, Education and Manpower Division, American Institute of Physics, State University of New York, Stony Brook

***Strong, Laurence E.,** Department of Chemistry, Earlham College, Richmond, Indiana

Strongin, Herbert, Science Department, West Wilson High School, Milbrae, California

Sullivan, Raymond, Department of Geology, San Francisco State College, San Francisco, California

***Sussman, Alfred,** Dean, College of Arts and Science, University of Michigan, Ann Arbor

Szabo, Michael, Department of Science Education, The Pennsylvania State University, University Park

Taylor, David W., Chairman of East School Science, Evanston Township High Schools, Evanston, Illinois

Taylor, Marie C., Department of Botany, Howard University, Washington, D.C.

Taylor, Moddie D., Department of Chemistry, Howard University, Washington, D.C.

Thomas, Barbara, Biology Teacher, Wakefield High School, Arlington, Virginia

Thompson, Ertle, Department of Science Education, University of Virginia, Charlottesville

Troyer, Robert J., Department of Mathematics, Lake Forest College, Lake Forest, Illinois

Tweeten, Paul W., College of Education, University of New Mexico, Albuquerque

Uffelman, Robert L., College of Education, University of Delaware, Newark

Vanaman, Sherman B., Chairman, Mathematics Department, Carson-Newman College, Jefferson City, Tennessee

Vavoulis, Alex, Department of Chemistry, Fresno State College, Fresno, California

****Viall, William P.,** College of Education, Western Michigan University, Kalamazoo; and Executive Secretary, National Association of State Directors of Teacher Education and Certification

Vodicka, Edward M., Division of Teacher Education and Certification, Texas Education Agency, Austin

***Voss, Burton,** School of Education, University of Michigan, Ann Arbor

Walch, Ray, Department of Education, Eastern Connecticut State College, Manchester

Walsh, Harold, American Chemical Society, Washington, D.C.

Walter, Robert I., Department of Chemistry, University of Chicago, Chicago

***Ward, Robert T.,** Graduate School of Education, University of Chicago, Chicago, Illinois

***Watson, Fletcher, G.,** Graduate School of Education, Harvard University, Cambridge, Massachusetts

Weitz, Joseph L., Department of Geology, Colorado State University, Fort Collins

Weller, Charles M., Department of Secondary Education, University of Illinois, Urbana

Westmeyer, Paul, Head, Department of Science Education, Florida State University, Tallahassee

Whinnery, J. R., Department of Electrical Engineering and Computer Sciences, University of California, Berkeley

Whitney, Robert C., Department of Physical Science, California State College, Hayward

Wilcox, Marie S., Department of Mathematics, Indiana University—Purdue University of Indianapolis

Will, Emery L., Director of Academic Advisement, State University College, Oneonta, New York

Willcox, Alfred B., Executive Director, Mathematical Association of America, Washington, D.C.

***Williams, Vernon,** Department of Mathematics, Rutgers—The State University, New Brunswick, New Jersey

Williamson, Stanley E., Department of Science Education, Oregon State University, Corvallis

Wimpey, John A., Director, Division of Teacher Education and Certification, Georgia State Department of Education, Atlanta

Wisner, Robert J., Department of Mathematical Sciences, New Mexico State University, Las Cruces

Withers, John D., Dean of Faculty and Instruction, Clark College, Atlanta, Georgia

Wixson, Eldwin, Chairman, Department of Mathematics, Plymouth State College, Plymouth, New Hampshire

Wolfe, Deborah P., Department of Education, Queens College of the City University of New York, Flushing

Yager, Robert E., Department of Science Education, University of Iowa, Iowa City

Yamamoto, Eugene H., Director, Recruitment and Employment, Hawaii State Department of Education, Honolulu

Young, Walter M., Department of Mathematics, Federal City College, Washington, D.C.

***Youtz, Byron L.,** Department of Physics, Evergreen State College, Olympia, Washington

Ziener, George H., Project Administrator, National Science Teachers Association, Washington, D.C.

Position

Biology
Beard
Bell, P.
Brumbaugh
Butler
Carter
Dean
Dieter
Durst
Feaster
Garth
Gross
Hoeksema
Hull
Jerkins
Johnson, R. M.
Kennedy
Kirk
Kormondy
Kowal
Lee
Lockard
Mayer
Novak
Olsen
Olstad
Ost
Petrucci
Robinson
Roseberry
Schein
Schmidt
Stegner
Sussman
Taylor, M. C.
Will
Williamson
Withers

Chemistry
Anderson
Borst
Campbell
Choppin
D'Arcy
DeRose
Dittmer
Estee
Farnum
Frank
Gardner
Gawley
Haenisch
Hanson
Herron
Kessel
King
Livermore
Postl
Pratt
Schubert
Settine
Strong
Taylor, M. D.
Vavoulis
Walsh
Walter

College Administrators
Coash
Dittmer
Gawley
Lange
MacMahon
Masla
Mayfield
Netzel
Peak
Rice
Stoever
Sussman
Will
Withers

Earth Science
Albritton
Coash
Hoff, D.
Holland
Huff
Pallrand
Pestrong
Rapp
Romey
Rusch
Samples
Shrum
Smith, J.
Stoever
Strongin
Sullivan
Weitz

Engineering
Bordogna
Maler
McNeary
Piel
Whinnery

Mathematics
Alder
Allen
Begle
Bell, M.
Blakeway
Blank
Brown, J
Carry
Cole, M.
Colvin
Cummins
Curry
Dessart
Dilworth
Dubisch
Ferguson
Fiasca
Fisch
Frisinger
Grossman
Halfar
Hardgrove
Heinke
Hess
Hestenes
Hiebert
Hillam
Hilzman
Hoff, W.
Hoskins
Hughes
Jackson
Johnson, R. L.
Jones, B.
Jones, P.
Kreider
Landin
Lay
Long
Maier
Mayor
McCamman
Meserve
Mock
Peak
Pedrick
Pfeifer
Phelps
Pignani
Pownall
Scandura
Schneider
Schult
Schulz
Scott
Smith, W.
Troyer
Vanaman
Walch
Wilcox
Willcox
Williams
Wisner
Wixson
Young

Organizations
Contee
Dasbach
Dieter
Eiss
Finigan
Foncannon
Greene, A.
Holland
Johnson, W.
Kormondy
Lightner
Livermore
Mayor
McCamman
Merrill
Phelps
Strassenburg
Viall
Walsh
Westmeyer
Ziener

Physics
Bents
Berkey
Bray
Correll
Cram
Dasbach
Davis
DiLavore
Dixon
Estin
Gottlieb
Greene, A.
Haber-Schaim
Holden
Ivany
Johnson, W.
Mayfield
Miller, J. D.
Netzel
Pallrand
Phillips
Prowse
Puri
Sandercock
Sands
Shamos
Strassenburg
Ward
Weller
Youtz

School Curriculum Projects
Begle
Bordogna
Bray

Conlon
Grossman
Haber-Schaim
Kennedy
Lee
Mayer
McNeary
Pallrand
Piel
Robinson
Romey
Samples

Science Education

Andersen
Armstrong
Benson
Bridgham
Brieske
Brown, S.
Burkman
Burnett
Conlon
Cossman
Deady
Eiss
Evans, T.
Fiasca
Gallagher
Gardner
Hoff, D.
Howe
Hurd
Irby
Irving
Ivany
Jacobson
James
Kochendorfer
Lacey
Lange
Lee
Lindquist
Mallinson
Masla
Mattheis
McAda
Morris
Newton
Okey
Ost
Pella
Piel
Schmidt
Shrum
Smith, J.
Stevens
Szabo
Thompson
Tweeten
Uffelman
Voss
Ward
Watson
Westmeyer
Whitney
Wolfe
Yager

Secondary School Personnel

Awkerman
Bellisario
Bixby
Blessing
Bradford
Brennan
Cole, L.
Connelly
Dalton
Davis, C.
DeRose
Evans, R.
Ferguson
Finigan
Hale
Harris
Haygood
Jones, J.
Keiffer
Lawrence
Merrill
Miller, W.
Nessman
Palmer
Rathert
Pfeiffer
Rissler
Rituper
Smith, F.
Smith, L.
Taylor, D.
Thomas

State Departments of Education

Biesecker
Briggs
Brooks
Browne
Charlesworth
Clark
Crider
Curtis
Domanowski
Drummond
Farmer
Fitzpatrick
Freeman
Garner
Greene, P.
Griffing
Grigsby
Hailey
Henderson
Hodges
Ireton
Kay
Latham
Lloyd
LoPresti
Mills
Morin
Nearhoof
Obradovich
Ortgiesen
Peterson
Pfau
Pier
Rucker
Ruff
Simandle
Sinclair
Dinst
Vodicka
Wimpey
Yamamoto

Students

Felton
Goodwin
Knapp
Mierwa
Parker
Reed

*Other**

Campbell
Colvin
Edwards
Gierl
Grambs
Irving
McGuire
Miller, M.
Schult

*NSF, Office of Education, Industry, Teacher Education, and Educational Laboratories

State

Alabama
Pratt
Settine

Arizona
Biesecker
Pfeifer

California
Alder
Beard
Begle
Bents
Bridgham
Brown, S.
Brumbaugh
Butler
Campbell
Coash
Deady
Dilworth
Gross
Grossman
Hestenes
Hughes
Hurd
Kirk
Lange
Lay
Lindquist
McAda
Merrill
Mierzwa
Miller, J. D.
Obradovich
Pedrick
Pestrong
Petrucci
Smith, F.
Strongin
Sullivan
Vavoulis
Whinnery
Whitney

Colorado
Bradford
Brennan
Carter
Correll
Fisch
Frisiginer
Johnson, R. L.
Jones, B.
Kennedy
Maler
Rissler
Robinson
Romey
Ruff
Samples
Weitz

Connecticut
D'Arcy
LoPresti
Walch

Delaware
Brown, J.
Lloyd
Miller, W.
Stegner
Uffelman

District of Columbia
Contee
Dasbach
Dieter
Eiss
Foncannon
Garner
Holland
Johnson, W.
Kormondy
Lightner
Livermore
Mayor
McCamman
McGuire
Ost
Phelps
Schubert
Schult
Taylor, M. C.
Taylor, M. D.
Walsh
Willcox
Young
Ziener

Florida
Adams
Bingham
Burkman
Choppin
Conlon
Westmeyer

Georgia
Puri
Shrum
Smith, L.
Wimpey
Withers

Hawaii
Yamamoto

Idaho
Armstrong
Briggs
Hilzman
Jones, J.
Kay

Illinois
Allen
Bell, M.
Connelly
Domanowski
Estin
Evans, R.
Felton
Gallagher
Goodwin
Hardgrove
Hoskins
Johnson, R. M.
King
Landin
Miller, M.
Mock
Nessman
Parker
Phillips
Reed
Schulz
Taylor, D.
Troyer
Walter
Ward
Weller

Indiana
Andersen
Grigsby
Haenisch
Herron
Kessel
Kochendorfer
Morris
Okey
Peak
Strong
Wilcox

Iowa
Cossman
Hanson
Hoff, D.
Nearhoff
Rathert
Yager

Kansas
Cram
Durst
Griffing
James

Kentucky
Scott
Simandle

Maine
Morin
Rice

Maryland
Browne
Cole, M.
DiLavore
Dixon
Gardner
Grambs
Greene, A.
Hale
Jackson
Jerkins
Latham
Lockard
Palmer
Schneider

Massachusetts
Ferguson
Finigan
Fitzpatrick
Haber-Schaim
Newton
Schmidt
Watson

Michigan
Hoeksema
Jones, P.
Knapp
Mallinson
Pfau
Sands
Sussman
Viall
Voss

Minnesota
Bray
Clark
Curry
Rapp
Stevens

Mississippi
Crider
Irby

Missouri
Bixby
Greene, P.
Novak
Rosebery

Montana
Hess

Nebraska
Curtis
Halfar
Ortgiesen

New Hampshire
Kreider
Wixson

New Jersey
Blessing
Gawley
MacMahon
Pallrand
Sinclair
Williams
Wolfe

New Mexico
Tweeten
Wisner

New York
Gottlieb
Ivany
Jacobson
Lacey
Masla
Piel
Pownall
Sandercock
Shamos
Strassenburg
Will
Wolfe

North Carolina
Blakeway
Farmer
Freeman
Mattheis
Pignani

North Dakota
Berkey
Farnum

Ohio
Cummins
Dean
Hailey
Heinke
Howe
Huff
Keiffer

Oklahoma
Hodges
Ireton
Lawrence
Rusch
Stoever

Oregon
Anderson
Davis, K.
Dittmer
Edwards
Evans, T.
Fiasca
Hiebert
Long
Maier
Mills
Postl
Williamson

Pennsylvania
Bell, P.
Bellisario
Blank
Bordogna
Charlesworth
DeRose
Holden
Rituper
Scandura
Szabo

Rhode Island
Borst

South Carolina
Awkerman

South Dakota
Estee
Pier

Tennessee
Benson
Dessart
Garth
Hull
Mayfield
Vanaman

Texas
Carry
Harris
Lee
Vodicka

Utah
Burnett
Hillam
Peterson

Vermont
Feaster
Meserve

Virginia
Brooks
Davis, C.
Hall
Haygood
Rucker
Thomas
Thompson

Washington
Colvin
Drummond
Dubisch
Frank
Long
Olsen
Olstad
Smith, J.
Youtz

West Virginia
Cole, L.
Hoff, W.
Kowal
McGinnis
Schein

Wisconsin
Brieske
Dalton
Gierl
Henderson
Irving
McNeary
Netzel
Pella
Pfeiffer

Wyoming
Prowse
Sindt
Smith, W.

APPENDIX G

PROFESSIONAL ORGANIZATIONS AND GROUPS REVIEWING THE GUIDELINES

Seventeen professional organizations or groups were invited to designate one or more persons to serve as liaison with the sponsors of this Project. These persons received copies of reports as they were developed and were invited to participate in one of the final three regional conferences. The liaison persons were asked to keep their organizations informed about the development and to comment on reports and to otherwise advise the Project Coordinator and Advisory Board. It should be understood that neither the agencies represented nor the individuals were asked to endorse the guidelines, as published.

American Association of Physics Teachers

JOHNSON, WILBUR, Executive Secretary, American Association of Physics Teachers, Washington, D.C.

LITTLE, ROBERT N., Professor of Physics, University of Texas in Austin, and President American Association of Physics Teachers

PHILLIPS, MELBA, Department of Physics, The University of Chicago, Chicago, Illinois

American Chemical Society

D'ARCY, HAROLD, Professor of Chemistry, Southern Connecticut State College, New Haven

WALSH, HAROLD, Education Office, American Chemical Society, Washington, D.C.

American Federation of Teachers

CONTEE, CARL, American Federation of Teachers, Washington, D.C.

ELWELL, JOHN, Washington Teachers Union, Washington, D.C.

NESSMAN, PAUL, Hubbard High School, Chicago, Illinois

Association for the Education of Teachers in Science

WESTMEYER, PAUL, President, Association for the Education of Teachers in Science, and Professor and Department Head, Department of Science Education, Florida State University, Tallahassee

Central Association of Science and Mathematics Teachers

TROXEL, VERNE, Department of Education, Oklahoma State University, Stillwater

Commission on College Physics

BRAY, EDMUND C., Minnesota Environmental Sciences Foundation, Inc., Minneapolis

CRAM, WINSTON, Department of Physics, Kansas State Teachers College, Emporia

GOTTLIEB, HERBERT, Martin Van Buren High School, Queens Village, New York

GREENE, ALAN C., Staff Physicist, Commission on College Physics, University of Maryland, College Park

HARRIS, JESSE M., Science Consultant, Dallas Independent School District, Dallas, Texas

MAYFIELD, MELBURN, Chairman, Department of Physics, Austin Peay State University, Clarksville, Tennessee

SANDS, RICHARD H., Department of Physics, University of Michigan, Ann Arbor

WELLER, CHARLES, Department of Science Education, University of Illinois, Urbana

Commission on Undergraduate Eduation in the Biological Sciences

WILLIAMSON, STANLEY B., Science Education Department, Oregon State University, Corvallis

Council on Education in the Geological Sciences

HOLLAND, R. D., JR., Director, Council on Education in the Geological Sciences, and Director of Education, American Geological Institute, Washington, D.C.

RAPP, GEORGE, JR., Department of Geology and Geophysics, University of Minnesota, Minneapolis

Mathematical Association of America

BEGLE, E. G., School Mathematics Study Group, Stanford University, Stanford, California

National Association for Research in Science Teaching

KORAN, JOHN, Department of Science Education, The University of Texas in Austin

SMITH, JOHN, Assistant Professor of Science Education, University of Washington, Seattle

WELCH, WAYNE, Associate Dean and Associate Professor of Educational Psychology, College of Education, University of Minnesota, Minneapolis

National Association of Biology Teachers

ANDREWS, TED, Dean of Environmental and Applied Sciences, Governors State University, Park Forest South, Illinois

YAGER, R. E., Science Education Center, the University of Iowa, Iowa City

National Association of Geology Teachers

THOMPSON, JOHN, Earth Science Teacher Preparation Project, Boulder, Colorado

National Commission on Teacher Education and Professional Standards

DARLAND, DAVID, National Education Association, Washington, D.C.

National Council of Teachers of Mathematics

MESERVE, BRUCE, Professor of Mathematics, University of Vermont, Burlington

National Science Teachers Association

BRANDOU, JULIAN, Director, Science and Mathematics Teaching Center, Michigan State University, East Lansing

EISS, ALBERT, National Science Teachers Association, Washington, D.C.

MERRILL, RICHARD J., Consultant in Secondary Curriculum, Mt. Diablo Unified School District, Concord, California

National Science Supervisors Association

FINIGAN, FRANCIS X., Winchester Public Schools, Winchester, Massachusetts, and President, National Science Supervisors Association

APPENDIX H

COMMITTEE MEMBERS

Committee on the Philosophy of Science and Mathematics Education
Claude Albritton
Burton H. Colvin
George W. Cossman
William Drummond
Magnus Hestenes
Barnabus B. Hughes
Paul DeH. Hurd, *Chairman*
Sigmund Mierzwa
Frank W. Smith, Jr.
Laurence E. Strong

Committee on the Breadth and Depth of the Science Teacher's Preparation in Science and Mathematics
James V. DeRose
Roy Dubisch
Michael Fiasca
Edward Haenisch
Warren Huff
L. Carroll King
William V. Mayer
Ingrith Olsen, *Chairwoman*
Carl Pfeiffer
E. J. Piel
William Romey
Sidney Simandle
Alfred Sussman
Robert T. Ward
Byron Youtz

Committee on Teacher Preparation and Strategies for the Teaching of Science and Mathematics
John A. Brown
Ernest Burkman
Charles Davis
W. Eugene Ferguson
David Fitzpatrick
Willard J. Jacobson, *Chairman*
Burton Voss
Fletcher G. Watson
Vernon Williams

Committee on the Breadth and Depth of the Mathematics Teacher's Preparation in Science and Mathematics
R. P. Dilworth
Phillip S. Jones
Mildred Kieffer
Norman Kowal
Orrin Nearhoof
George Pedrick
Malcolm W. Pownall, *Chairman*

Advisory Board of the Project
William L. Charlesworth
J. P. Freeman
Addison E. Lee
Arthur H. Livermore
John R. Mayor, *Chairman*
David H. Ost
William P. Viall

NOTES

1. John W. Gardner, *No Easy Victories*, Harper Colophon Books (New York: Harper and Row, 1968), p. 71.
2. John W. Gardner, *op. cit.*, p. 70.
3. Arnold Toynbee, "The Graeco-Roman Civilization," *Civilization on Trial*, Meridian Books (New York: World Publishing Company, 1958), p. 50.
4. A. M. Cartter, "University Teaching and Excellence," *Improving College Teaching*, C. B. T. Lee, ed. (Washington, D.C.: American Council on Education, 1967), p. 160.
5. Environmental Studies, *Environmental Studies Packet #1*, Boulder, Colorado, 1971, p. 5. (Available from American Geological Institute, 2201 M Street, N.W., Washington, D.C. 20037.)
6. R. L. Wilder, "The Beginning Teacher of College Mathematics," *Effective College Teaching*, William H. Morris, ed. (Washington, D.C.: American Council on Education, 1970), p. 95.
7. Howard H. Cummings, ed., *Science and the Social Studies*, Twenty-seventh Yearbook of the National Council for the Social Studies (Washington, D.C.: The Council, 1957), p. 8.
8. Optimization may be defined as the idea of a "best" solution to a problem or course of action; the development of constraints and criteria as effective means toward making value judgments and decisions among various alternatives.
9. J. Lawrence Walkup, "The President's Address," Annual Meeting of American Association of Colleges for Teacher Education, Chicago, 1970.
10. R. L. Wilder, *op. cit.* (see Note 6), p. 102.
11. *The Pre-Service Preparation of Secondary School Biology Teachers*, Addison E. Lee, ed., Publication 25 of the Commission on Undergraduate Education in the Biological Sciences, June 1969. (Available free of charge from CUEBS, 3900 Wisconsin Avenue, N.W., Washington, D.C. 20016.)

    Preparing High School Physics Teachers, Report of the Panel on the Preparation of Physics Teachers of the Commission on College Physics, January 1968. (Available from ERIC Document Reproduction Service, Accession Number ED 029 775.) A revised report available summer 1971 from the American Association of Physics Teachers, 1785 Massachusetts Avenue, N.W., Washington, D.C. 20036.

    Recommendations for the Training of Teachers of Mathematics, Committee on the Undergraduate Program in Mathematics, January 1961, revised 1964 and 1966. A new edition will be available at an early date. Address inquires to CUPM, P.O. Box 1024, Berkeley, California 94701.

    Recommendations for the education of secondary school earth science teachers can be found in the *Journal of Geological Education*, vol. 14, no. 1 (February 1966). Specific articles are: William M. Merrill and John W. Shrum, "Planning for Earth Science Teacher Preparation," pp. 23-25; John W. Shrum, "Recommendations for a Basic Academic Preparation for Earth Science Teachers," pp. 26-28; and William M. Merrill, "Recommendations: Academic Preparation of Secondary School Earth Science Teachers," pp. 29-32.

    "Guidelines for Content of Pre-service Professional Education for Secondary School Science Teachers: A Statement by the Association for the Education of Teachers in Science and the Cooperative Committee on the Teaching of Science and Mathematics," *The Science Teacher*, vol. 35, no. 5 (May 1968), pp. 85-90.
12. Morris Kline, *Mathematics and the Physical World* (New York: Thomas Y. Crowell, 1959), p. 12.
13. *Recommendations for the Training of Teachers of Mathematics*, Committee on the Undergraduate Program in Mathematics (see Note 11).
14. David P. Ausubel, *Educational Psychology: A Cognitive View* (New York: Holt, Rinehart, and Winston, 1968), frontispiece.
15. Morris Kline, *op. cit.* (see Note 12), p. 475.
16. Henry O. Pollak, "Applications of Mathematics," *Mathematics Education*, 69th Yearbook of the National Society for the Study of Education (Chicago: University of Chicago Press, 1970), p. 319.
17. Engineering Concepts Curriculum Project, Man-Made World, final edition (Manchester, Mo.: McGraw-Hill, Webster Division, 1971).
18. Ben Noble, *Applications of Undergraduate Mathematics* (New York: Macmillan Co., 1967).
19. This publication is available from the Committee on the Undergraduate Program in Mathematics, Berkeley, California. (See Note 11.)
20. John W. Gardner, *op. cit.* (see Note 1), p. 73.
21. Robert M. Gagné, *The Conditions of Learning* (New York: Holt, Rinehart and Winston, 1970), p. 1.
22. Robert M. Gagné, *op. cit.*, p. 244.
23. Alfred North Whitehead, *Science and the Modern World* (1925) (New York: New American Library, 1962), p. 76.
24. Fred T. Wilhelms, *Realignments for Teacher Education*, 1970 Yearbook, American Association of Colleges for Teacher Education (Washington, D.C.: The Association), p. 71.
25. John Dewey, *Logic: The Theory of Inquiry* (New York: Holt and Company, 1938), p. 108.
26. Environmental Studies, *op. cit.* (see Note 5), p. 4.
27. Robert M. Gagné, *op. cit.* (see Note 21), p. 244.
28. Paul Woodring, *New Directions in Teacher Education* (New York: Fund for the Advancement of Education, 1957), p. 62.
29. John W. Gardner, *Self-Renewal*, Harper Colophon Books (New York: Harper and Row, 1964), p. 81.
30. The recommendations of the Committee on the Undergraduate Program in Mathematics (*op. cit.*) should be consulted.
31. The reader is referred to *Improving Educational Assessment and An Inventory of Measures of Affective Behavior* by the American Association for Supervision and Curriculum Development (1201 Sixteenth Street, N.W., Washington, D.C. 20036) for a listing of measures of affective behavior.

    See also *Annual Self Inventory for Science Teachers in Secondary Schools*, First Edition, 1970, by the National Science Teachers Association (1201 Sixteenth Street, N.W., Washington, D.C. 20036).