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VIEWPOINTS ON UNDERGRADUATE COLLEGE SCIENCE PROGRAMS.
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THE TEXT OF SPEECHES AND DISCUSSION GROUP REPORTS FROM THREE CONFERENCES CONCERNED WITH COLLEGE SCIENCE PROGRAMS ARE INCLUDED IN THIS PUBLICATION. THE SPEECHES ARE DIRECTED TO SUCH TOPICS AS (1) THE UNITY OF SCIENCE, (2) CHANGES IN SCIENCE EDUCATION, (3) SCIENCE AS A PART OF GENERAL EDUCATION, AND (4) THE RELATIONSHIP OF THE SCIENTIFIC ENDEAVOR TO MANKIND. REPORTS AND SHORT ADDRESSES FROM DISCUSSION GROUPS INCLUDE (1) SCIENCE IN GENERAL EDUCATION, (2) SCIENCE FOR ELEMENTARY TEACHERS, AND (3) PREPARATION OF COLLEGE MAJORS IN THE SCIENCES. (RS)

VIEWPOINTS ON UNDERGRADUATE COLLEGE SCIENCE PROGRAMS

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FOREWORD

This publication is a report of three conferences on college science teaching which were held during the 1964-65 academic year. Several of the addresses as well as summaries of the various discussion groups contain items that are significant for college administrators and professors who are interested in improving the quality of college science instruction. These ideas are presented, not as a definitive guide for action, but as the considered statements of individuals and knowledgeable groups.

The Editor wishes to acknowledge the excellent work done by the conference participants, the efforts of Mary Hawkins of the NSTA staff, who edited the final manuscript, and the other members of the NSTA staff, who assisted in producing this publication.

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Albert F. Eiss, Editor
Associate Executive Secretary
National Science Teachers Association

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INTRODUCTION

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The purpose of this publication is to take a critical look at the collegiate undergraduate science program. The National Science Teachers Association and its Commission on the Education of Teachers of Science are concerned with this problem because of the high significance that undergraduate science programs have for the preparation of elementary and secondary school teachers. The criticism of the work of high schools and elementary schools, to which scientists have been especially prone, seems in very poor taste if we are not at the same time willing to subject the education in science offered at the college level to the same critical and objective examination.

The National Science Foundation and other agencies have funded curriculum studies which are having a tremendous impact on the elementary and secondary school science curriculum. If these projects attain, even partially, the objectives which their originators proclaim, they have far-reaching implications for the science taught at colleges and universities. A student who has had the advantage of a modern high school program is quite unlikely to be happy with a traditional college program. It is fair to ask whether college programs have really kept pace with changes in the elementary and secondary schools.

Another question I would like to pose is, "Who teaches the undergraduate student?" It happens that I was an undergraduate at a major university. During the course of my undergraduate career, I had the good fortune, at various times, to have had as teachers the head of the physics department, the head of the botany department, and the head of the zoology department. One of these was an international authority in his field. I wonder how many undergraduates today can boast that they have had even a full professor as an instructor. In many of our major institutions there are sophomores who have never had so much as an assistant professor as instructor! The implications of these observations I leave to you.

As an educator, I am concerned about still other problems. I recall the indictment of a distinguished dean who observed that

St. Thomas Aquinas would have been happy with the typical college science program. He averred that it was taught as dogma. If elementary school children are to be concerned with science as process, why not expose college students, particularly those who will become teachers, to a similar learning experience? I believe there should be less telling and more doing and showing in college science programs. If undergraduates experience the kind of science they should have, there should certainly be little excuse for a long continuation of the expensive inservice retooling operation of recent college graduates we are witnessing through the institute programs. Other questions relate to the value of non-laboratory science courses for general education or for prospective elementary teachers. A good many scientists and educators will insist that "non-laboratory science" is a contradiction in terms. At the secondary level, what about the suitability of typical academic majors for teaching compared to preparation for graduate work? Should not both of them have broader base? As a final question, I would ask whether the present undergraduate prog. is not being sacrified on the altar of graduate study and research.

It is certainly proper to examine the state of undergraduate collegiate science instruction. It is clearly the hope of the sponsoring agencies that the close relationship between the undergraduate science curriculum and the quality of teacher preparation for elementary and secondary schools would be in the foreground throughout the pages of this publication. However, we should not forget that there is also a need for improved teaching techniques and more imaginative approaches to instruction at the college level. It is proper that this should be done by the teachers of science.

The present publication is divided into two parts. The first part consists of the major addresses presented at the three college and university conferences held during the 1964-65 academic year. The addresses cover a wide range of problems related to science education. The authors, with one exception, are not science teachers but are concerned with the products of the undergraduate science program--the graduates who go to graduate school or begin work in industry. The second part deals with more specific problems related to planning and teaching undergraduate science courses. The summaries of discussion groups represent the reactions of the participants in

the conferences and include excellent suggestions for revising and improving science courses.

The materials in the following chapters should be of interest to a very wide audience. Although the content is directed primarily to college science instructors, many observations will be of interest to those who are concerned with methods courses and other professional education courses.

Scientists and college science teachers provided the impetus for change in elementary and secondary school science that has resulted in a major overhaul of the curriculum. Perhaps the same groups can turn their attention to the college program and begin an equally drastic and comprehensive revolution. It is hoped that they will be as objective in their thinking and as receptive to innovation in considering problems related to college science teaching as the elementary and secondary teachers have been with their curriculums.

PART I. MAJOR ADDRESSES

SEEKING UNITY IN SCIENCE

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It is a privilege to participate in this conference for college teachers of science sponsored by the National Science Teachers Association. Since I spent some eighteen years of my professional life in the teaching of physics at both the undergraduate and graduate levels, I like to feel that I am appearing here as one of your colleagues in the science teaching profession.

On the other hand, I regret that the exigencies of World War II terminated my active teaching career--and I have been engulfed in the problems of research and university administration ever since. I must, therefore, appear before you as an "emeritus teacher," but still as one who has been able to retain close contact with science education.

I always took special pleasure in teaching the introductory courses in physics at the freshman and sophomore level, and I never allowed myself to be removed from the introductory teaching program. I found introductory teaching especially rewarding for two reasons. First, because I always cherished the hope that a few of my students would proceed from the introductory into the more advanced courses--and some would go on to professional careers in science. It was always a rewarding pleasure to see this happen.

At the same time, I realized always that most of the students would probably not go into scientific careers, and I always found it an inspiring challenge to bring such students into contact--possibly for the first and also for the last time in their formal education--with the important basic concepts and the exciting great ideas in the field of science. I was convinced then, and am even more convinced now, that a good introduction to the ideas, concepts, and methods of science should be an essential feature of the education of every college student, regardless of his future career objectives.

It is a sad day for a nation like the United States if a majority of its college-educated population is illiterate in science. Such illiterates--and we know there are only too many of them in our population today--have not only missed a great personal opportunity for understanding and appreciating some of the great scientific adventures of our time, but they are also depriving themselves of the opportunity of becoming more informed and more useful citizens of a country in which scientific and technological developments constitute a dominating feature of our national life.

There are those in our society who believe that the rapid development of science has been a bad and not a good thing for this country and for the world. However, I am sure it is a thesis accepted by all members of this audience that science and technology have enormous benefits to contribute to the welfare of human society and that our danger lies not in our knowledge of science, but in the lack of knowledge on the part of citizens, voters, and political

leaders. Science is not a danger or threat, but scientific illiteracy is.

I take it that the major purpose of this conference is to discuss ways not so much for improving the education of professional scientists, but to reduce the scientific illiteracy of our college population by providing a suitable educational experience in science to all students.

Unfortunately, I fear that we in the colleges have not evolved adequate programs for achieving this goal. We often are accused of giving all our attention to the prospective professional scientists--and too little attention to the ninety percent or so of college students who will not pursue scientific careers.

Obviously, I am not competent to suggest a panacea for solving this problem--and indeed I am sure that no panacea exists. I am, however, sure that we can make substantial improvements in the current situation.

I am going to suggest that possibly a key to this problem may lie in a recognition of how science has changed during the past thirty years. It may seem strange that I suggest that this offers us a key to our solutions, for it is normally agreed that there has been an enormous scientific explosion during these years and an enormous proliferation in various scientific specialties. This explosion of knowledge may, at first sight, seem to have erected a serious barrier toward providing anything like an adequate introduction to science to students who are not going to devote a large fraction of their undergraduate experience to scientific subjects. Indeed, we do face this barrier if our goal in general education is to present the nonscience students with large segments of factual material in the various scientific disciplines. There is no hope of providing, even to the scientific specialist, more than a brief glimpse of the vast array of scientific knowledge which now exists in the many scientific fields. And we, as teachers, will be butting against a stone wall if we attempt to move in this direction.

Fortunately, however, we do not have to proceed down the blind alley of trying to cram more and more scientific facts into a limited curriculum. There has been another important--yes, an even more important--trend in modern science. This is the trend of unity which has accompanied the trend of diversity or proliferation. It is indeed a very remarkable phenomenon that a new unity has come to pervade science. When biology consisted of classifying different genera and species of plants and animals; when geology consisted primarily of the classification of rocks and structures; when chemistry consisted in learning reactions and formulas; and physics was largely a study of pulleys, levers, and electric circuits, the unity in science was perhaps less than obvious.

But today it is evident that the universe of science is a physical universe. It is a universe governed by a rather modest number of basic physical principles--broad basic principles which underlie a multifarious array of special exemplifications and applications. Thus, the modern geologist is studying the physical structure and the physical processes which take place within the earth--

and, in modern extensions, within the moon and the planets. The biologist is studying the nature of life at the molecular level, seeking to understand the basis of genetics and life development in terms of molecular structure and processes. And the chemist has long known that the basis of his science is the study of how individual atoms or groups of atoms attract or interact with each other. And, as everyone knows, the whole modern science of astronomy is really described by the name "astrophysics"--physics on a very large scale.

I like to think of the entire physical universe as being bound together, or correlated, through a series of four different notions or concepts or sets of principles. These are:

1. The concept and laws of force
2. The concept and laws of motion
3. The concept and laws of energy
4. The concept and laws of change

To illustrate the unifying significance of these four concepts, let me describe each one briefly.

1. The concept of force. Curiously enough, force, while it is one of man's most elementary experiences, is still a fairly sophisticated concept, the elucidation of which began only with the brilliant work of Isaac Newton. We now know that there are surely three, and probably no more than three, basic kinds of forces in the universe:

1. Gravitational forces
2. Electromagnetic forces
3. Nuclear forces

Possibly some day we shall know that these three kinds of forces are really three aspects of some deeper concept of force--but at the present these three forces seem essentially unrelated.

We are all familiar with the gravitational forces first proposed by Newton and how they are the governing forces in large-scale phenomena, such as those encountered in astrophysics, in celestial mechanics, and in geophysics. Basically, gravitational forces are extremely weak forces. The gravitational force between two protons, for example, is wholly negligible in atomic and nuclear reactions. But, since gravitational forces are always attractive (no two particles have a gravitational repulsion), these forces are also additive so that when very large masses of matter are concerned the total gravitational forces between them can be colossal indeed. By the same token, gravitational forces are long-range forces. The force field falls off only as the inverse square of the distance between attracting bodies; gravitational fields can be all-pervading fields stretching for millions of miles--indeed, millions of light years--out through the universe. Although the simple gravitational theory of Isaac Newton has been modified by Einstein's general theory of relativity, gravitational forces still remain the basic forces which constitute the "glue" holding the universe together. The interest in gravitational forces has, of course, been greatly accelerated through recent developments in space exploration, since exact knowledge of gravitational fields is essential to the precise calculation

of trajectories of space vehicles.

A second type of force somewhat more closely related to everyday matters concerning the chemist and biologist, is the area of electromotive forces. These include the simple electrostatic forces of attraction and repulsion between charged particles, the magnetic forces between magnets or two electric currents, and the more subtle exchange forces--or what we used to call "chemical forces"--which arise in quantum electrodynamics. Electrostatic forces hold individual atoms together, binding the negative electrons to the positively charged nucleus. These forces and the exchange forces hold atoms together in groups or molecules, including the extremely large molecules such as DNA, recently revealed to be the critical element in living processes.

Electromagnetic forces are very much stronger than gravitational forces, the electrostatic repulsion between two electrons, for example, being vastly greater than the gravitational attraction. Electrostatic forces also obey the universe square law, but these forces are not nearly so pervasive in space as the much weaker gravitational forces because of the fact that they are exhibited both as attractive and repulsive forces. Since electrical charges can be both positive and negative and since positive and negative charges are in about equal numbers in the universe as a whole, the electrostatic forces between two bodies generally are substantially canceled out, the attractive forces between unlike particles and the repulsive forces between like particles being substantially equal.

This is much less true of the so-called "magnetic" forces. Because of the tendency of magnets to line up--and therefore reinforce their total force fields--magnetic forces seem to be of great importance in astrophysics, and seem to be very pervasive forces indeed within the various galaxies and for vast distances around certain types of stellar objects. The motion of charged particles in these vast magnetic fields in space may be a principal source of the high-energy cosmic rays which continually bombard the earth. They are surely the source of many of the powerful electromagnetic waves of radio wavelengths with which the radio astronomers deal.

On a more earthly scale, electromagnetic forces are clearly of vast importance in modern technology, and on the basis of these forces we have built our vast structure of electric technology and communication technology. And in atomic and molecular physics and chemistry they are essential to understanding the nature and structure of atoms, molecules, crystals; of solids, liquids, and gases.

Nuclear forces are in many ways the most mysterious and unfamiliar of all force fields. They apparently have two classes: the so-called "strong" interactions and the "weak" interactions. The strong interactions, such as the force between two neutrons, are strong indeed when the distances are very small. But nuclear forces have the property of falling off extremely rapidly with distance, and are thus extremely short-range and nonpervasive forces. They are the controlling forces, however, in nuclear structure and in particle physics. The study of the nature of the weak and strong nuclear forces is one of the basic current problems in physics--

though it is a problem of lesser concern to the chemist and the biologist. Existence of such forces, however, is essential to a basic understanding of our physical universe. It is, for example, the nuclear reactions governed by these forces that take place within the star that are the major source of energy in the universe, and the source of energy which makes the earth a place where creatures can live.

2. The concept of motion. Leaving the concept of force, we may examine briefly the concept of motion--again apparently a simple and elementary concept, it has subtleties which only Newton and Galileo first revealed and which were only fully understood on the basis of the theory of relativity. All the universe is in motion--from the nuclei within atoms to the atoms within a molecule, to the planets around the sun, to the stars, the galaxy, and the galaxies relative to each other. Since motion is intimately tied with force--through Newton's laws of motion and Einstein's theory of relativity--some might suggest that force and motion are two aspects of the similar concept. For our purposes, however, it is best to treat them separately and to think of motion in all its aspects--from earthquakes to the expanding universe; from processes in the nucleus of a cell, vibrations in a crystal, electrons along a wire--as one of the basic unifying concepts in science. Some understanding of the nature of motion and the laws of motion is essential to every scientific discipline and to the understanding of nearly every phenomenon of interest to humans--from the driving of a car to the travel of a spacecraft toward Mars.

3. The concept of energy. This concept, in a sense, is a direct result of the laws of force and the laws of motion but, since it is a concept of such all-pervading validity and since it is a concept that carries with it an all-pervasive and unifying quality, the idea of the conservation of energy is one of the great physical principles. It applies inside the living cell as well as within the swirling galaxy; in the deep interiors of the stars and inside the nuclei of atoms. Without the concept of energy and its conservation, our whole civilization of machines becomes incomprehensible. It is a connecting link between biology and astrophysics; between pure science and technology.

4. The concept of change. Change, if you wish, is an exemplification of motion. And, indeed, change on the macroscopic scale can usually be related to motion on the microscopic or atomic scale. Change is involved in the law of conservation of energy, but it is also involved in the second law of thermodynamics--the law of entropy. The second law of thermodynamics, like the first law, or the conservation of energy, is a unifying and simplifying concept. It is easier to use the second law of thermodynamics to predict how a gas will behave on expansion than to try to compute in detail the individual motions of all the particles which make up the gas. But the law of entropy helps us understand all natural processes--from the evolution of a star to the evolution of a living system. Change is, again, a pervasive quality of the universe, and occupies our attention every day on both the macroscopic and the microscopic scale.

Now I think I have elaborated my subject sufficiently to bring out the point I am trying to make--namely, that the teaching of science

should stress the unity of science rather than its diversity, or rather should express the diversity as exemplifying an underlying unity. It is, I believe, perfectly possible, if we are intelligent, to give every college student some concept of the basic principles which I have been discussing and some idea of the ways in which these principles apply to every scientific discipline. To bring this vague idea into concrete form in terms of actual courses and textbooks, I realize, is a tremendous job. I realize also that I am not the first one to propose this task, nor to advocate it, and I know that many are working along these lines. College teachers and university research scientists are indeed collaborating in many projects aimed generally at these goals. I hope that soon another forward step can be taken in this collaboration in bringing the unifying aspects of science together in a practical form which all college students can grasp, and which will indeed be stimulating and exciting to them.

THE CHANGING FACE OF SCIENCE EDUCATION

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The rapidity with which the face of science is changing is amply illustrated by taking note of a few of the recent scientific developments that have been presented to the public in newspapers and magazines. Scientists have found evidence to support the idea that plastids in plant and animal cells have hereditary properties. The effect of solar winds on quasars appears to have been established. An artificial gill has been produced that permits gases to pass through a membrane but prevents the passage of water through the membrane. Evidence is being obtained that suggests an electron can be hydrated in a fashion somewhat similar to that of the hydration of a proton. Recent discoveries continue to support the assumption that liquids have structure. Kinetic studies involving isotopic ex-exchange procedures continue to provide information concerning the mechanism and nature of complex ion information. A few high school students have become interested in such topics as the implications of neutron activation, the potential of lasers, the significance of the biochemical aspects of genetics, and the future possibilities of the applications of fuel cells. Thus, one can see that laymen, scientists, and science students are directly concerned with the modern advances of science. Each of these scientific discoveries in itself reflects the constantly changing face of science.

What factors are contributing to this rapidly changing face of science? The quantity of new scientific information becoming available continues to increase at an unbelievable pace. Some people have predicted that in the next five years our basic knowledge of physics will double. Others have predicted that the chemical information known today will double in the next seven years. From all indications, our biological knowledge is increasing at an even more rapid rate. Without attempting to consider the value of the material being published, one recognizes that the known scientific information is increasing at a remarkable rate. The appearance of this avalanche of information is not surprising when one considers that of all the scientists that have lived since the beginning of time, 95 percent of them are alive today. Furthermore, the total annual research expenditures of government and industry are greater than all the funds used for research prior to World War II. One would expect that the quantity of published research findings would inevitably continue to increase each year.

How does this rapid accumulation of scientific information affect the preparation of teachers? Let's consider the problem confronting the college and university professors in attempting to present modern-day science to the students in their courses. Although authors incorporate as much of the new information as possible into their textbooks, some of the material in a textbook is out-of-date before the book is published. The introduction of paperbacks has alleviated this problem to some extent but has not eliminated the problem. Consequently, the textbook that is being used must be supplemented with information taken from the current scientific literature.

In many cases, the professors do not have access to a sufficient number of journals to be able to keep abreast of the current developments in their fields. Herein lies one of the major problems facing us today.

Considerable thought is being given to ways in which college and university professors can become acquainted with recent developments in their fields. A method of "retreading" professors must be developed and initiated in the near future if we hope to present modern-day science to our students. From the point of view of preparing secondary school science teachers, it becomes essential that these prospective teachers be given courses containing modern-day science. The individual entering teaching today must be acquainted with as many of the new scientific developments as possible. There is no reason why beginning teachers should have to attend a summer institute after one or two years of teaching to become familiar with recent advances in their major field of science.

When one realizes the impossibility of presenting to the students all of the available information in a particular field of science, one must decide what should be the content of undergraduate science courses. In considering this problem, there are several questions to which you might like to give some thought. Has the useful content been selected for presentation in your existing undergraduate science courses? Does the nature of these undergraduate courses provide the most effective presentation of the subject material? Is the current curriculum the most effective curriculum that can be established for presenting science to your students? Probably the questions that we should raise are: What shall we teach? How shall we teach? In what order should the content of a particular subject be taught?

Examination of some of the trends of recent course content improvement and curriculum development activities would appear to be useful from the point of view of the objectives of this conference. Consider some of the features of the courses initiated under the Course Content Improvement Section of the National Science Foundation. Although the courses have been developed for use in presenting science in secondary schools, the philosophy used in constructing these courses is quite applicable to an undergraduate science curriculum for training secondary school science teachers. These courses have been developed using the conceptual approach to the subject matter, that is, the courses are structured around a group of concepts and principles. A group of seemingly unrelated facts is organized through the consideration of a particular concept. Through such an approach, the students can be encouraged to recognize not only the relationship between a series of facts but also those relationships existing between different concepts. As new information is introduced to the students, they frequently have to reorganize the facts and even modify a concept previously considered. Assertion is replaced by a discussion of an idea so as to permit the student to discover the concept and the resulting relationships.

I should like to call your attention to the excellent booklet entitled "Theory Into Action in Science Curriculum Development," published by the National Science Teachers Association. This booklet has three parts, one entitled "Toward a Theory of Science Education

Consistent with Modern Science," written by Professor Paul deHart Hurd of Stanford University. A second, "Conceptual Schemes and the Process of Science," was prepared by a committee of scientists at an NSTA conference under the chairmanship of Professor Randall M. Whaley, Vice President for Graduate Studies and Research at Wayne State University. The third part of the booklet is entitled "Planning a Local Action Program for Implementing Curriculum Development in Science." This document contains excellent considerations of the over-all aims and philosophy of a modern-day science education program. The description of the conceptual schemes shows quite clearly the use of this approach in presenting science. There are many features of the section dealing with the local action program that could be incorporated advantageously and easily into local teaching situations. I urge you to obtain a copy of this booklet1/ and to study its contents carefully. I am certain that you will find the ideas presented to be very interesting and useful to you.

Some of the other major features of the new courses include the presentation of a subject from both the experimental and theoretical points of view. The students are shown what we know and what we believe, the so-called "fact and fiction idea" of science. The interplay and interaction between experimentation and theory are well documented and illustrated. In all of these courses, the laboratory work plays a major role in the development and establishment of the lecture material being concurrently presented. The laboratory work is usually of the research-centered open-end variety presented so that the student becomes directly involved in an investigation in which a basic concept or a major principle is emphasized. Abstract thinking is another important feature of these courses. The students formulate a series of assumptions from which they develop a model that can be either a mathematical equation or a qualitative physical representation. After testing the model and determining its applicability, the students modify the original assumptions and alter the model in view of the new evidence. The model is again tested and special attention is given to the limitations of the model.

Throughout these courses, the element of discovery is used to good advantage. By discussing a concept or unifying principle, the students develop a deeper understanding of the concept or principle. The unknown is presented to the students as a challenge in an effort to establish the fact that the scientists do not have solutions to all of the existing problems nor the answers to all the questions that might be raised about the nature of matter. The courses provide the proper environment and create the necessary attitude to encourage the students to make predictions. The students are confronted with situations not previously considered and are asked to resolve problems or answer questions related to these situations. By using intuition or educated guessing and by reasoning by analogy, the students suggest a possible solution to a problem.

In summary, the new courses emphasize concepts rather than factual information. The students develop an understanding of the concepts that enables them to gain a deeper insight into the subject

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1/ Available from National Science Teachers Association, 1201 Sixteenth Street, N. W., Washington, D. C. 20036. Price $1.50.

being presented. The philosophies and attitudes of science are developed as an intricate part of the content and not as isolated, unrelated material. In your discussions, appropriate attention should be given to the advantages and disadvantages of organizing undergraduate science courses along these lines.

What are some of the changes that are being made in science curricula that should be given consideration in preparing secondary school teachers? More attention is being given to the horizontal versus the vertical development of subject material. Serious thought is being given not only to the most logical sequence of courses, but also to the most desirable content of a specific course. Of increasing significance is the role that independent study plays in the undergraduate training of students.

One of the questions that must be answered is, how soon in a four-year program should independent study be initiated? As the science and mathematics high school background of the entering student improves, the nature of the first-year courses in science becomes increasingly important. Ideally, advantage should be taken of the better background that these students possess.

Repetition of high school experiences must be avoided if we hope to retain as majors those freshmen who registered as science majors. Many institutions have found it possible to alter appreciably their first-year courses in science. Flexibility within the curriculum is becoming more important. The offering of advanced placement to well-prepared entering students continues to increase. In such situations, the nature of the second-year course must be such that those students granted advanced placement can be accommodated without being penalized. Students who have completed a basic core of courses in their major field should have an opportunity to select additional courses, including independent study. One of the most critical areas of the curriculum that is being given considerable attention is the nature of the laboratory work associated with the courses. There is a trend toward the vertical development of laboratory work so that the degree of sophistication of the laboratory investigations in the junior year is much greater than that given during the sophomore year.

In your deliberations during this conference, you should consider the desirability of altering the content and organization of a science curriculum. Of equal importance is the question of how methods of instruction can be changed to provide for large groups of students. Your discussions should proceed on the basis that the traditional sequence of courses in a curriculum is historically centered rather than logically ordered. Of equal importance is the question of what other science and mathematics courses a specific science major should take outside his major field. If any specific recommendations pertaining to curricula come forth from your discussions, our conference will have been successful.

Let's look into the future and see what the teaching of science might be like in ten years. Forecasting is a dangerous business, as any weatherman can tell you. Thomas Jefferson, in announcing the Louisiana Purchase, felt that the territory might be fully occupied

in 25 generations (2600 AD). Sir William Crookes in 1898 foretold imminent starvation for the human race through diminishing supplies of nitrogen. In spite of the dangers of forecasting, let's look at the role of the teacher in the classroom of tomorrow.

In the future, there will be three types of teaching--training in mental skills, training in manipulative techniques, and education. The mental skills that currently are established through drill in a classroom and at the chalkboard will be handled through programed instruction in the future. The writing of chemical formulae, the writing of simple chemical equations, and chemical arithmetic will be presented through programed instruction materials. The role of the teacher in presenting these skills will be minimal. Many teachers of today have been trained to present subject matter through the process of drill. What will they teach tomorrow if drill is handled through programed instruction? The training of students in the future will involve the development of techniques which in many cases will be accomplished through the use of film loops or filmstrips as supplementary materials associated with laboratory work. Again, we could ask how the teacher of today will adjust to the task of training students in these terms.

The major role of the teacher in ten years, however, will be concerned with the education of students. The teacher will be responsible for presenting the material in such a way as to give the students an understanding of the subject. The teacher will no longer be primarily concerned with the presentation of factual information, but will be more concerned with developing relationships between those basic concepts and principles which will give the student a deeper insight into the subject matter. The student being trained to be the teacher of tomorrow will need a type of preparation different from that which we have been giving to the students in the past, if the teacher is going to educate students. Very few science methods courses of today will be adequate for training the teacher of tomorrow who will be responsible for educating students. This is another area to which you should give some thought.

During this conference, we are going to consider various aspects of teacher preparation for secondary school science. We cannot afford the time to discuss the effectiveness of methods for preparing students to be teachers of yesterday or today. We must consider what type of teacher we wish to have in the classroom tomorrow and what changes must be made in our science programs to prepare the teacher of the future. In your deliberations, think big! Consider the ideal situation, and don't allow your deliberations to become limited by the problems of yesterday or today.. Think constructively with a positive attitude. For the present, neglect the cost of the changes that you wish to recommend. Consider the type of science program that you would establish if someone gave you a million dollars to finance the operation. Look into the future and decide what the ideal educational program should be for students preparing to teach in the classrooms of tomorrow! Look forward--not backward. What kind of teachers would you like to see in the classrooms of tomorrow?

WHENCE AND WHITHER SCIENCE EDUCATION?

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Training programs for the employees of industry are very commonplace nowadays. However, most of these training programs are aimed at the development of specific skills of shop operators, technicians, and craftspeople. Less commonplace are industrial training programs which aim at employee training at levels which are equivalent to undergraduate college level, and fewest of all are training programs which are pitched at the truly graduate university level. My company's chief interest, however, is in training of the last variety, graduate level science and engineering training for professional staff employees. I administer these programs at Bell Laboratories and have a great deal to do with policy direction as well. I don't think there are in this country more than a couple dozen people whose jobs are quite exactly like my own. It occurred to me, therefore, in preparing for this conference, that I might be able, because of the near uniqueness of my job, to bring you some thoughts on science and engineering education which are different from the thoughts which a university educator would bring you, and different again from those of a practicing scientist who went through the training process 20 or 30 years ago.

The teaching of science, engineering, technology, and mathematics at all levels has been in a state of tremendous flux during the past decade and shows every indication of continuing this evolution in the decade to come. This flux has resulted in a number of new philosophies and directions. Some of these have come far enough along to give us some idea of their effectiveness, but have not yet solidified into a pattern so rigid as to be incapable of further redirection. This is a good time, therefore, for a stocktaking. And, indeed, the theme of this conference, "Product and Process in Science Education," suggests just such a general overlook at whence we have come and where we seem to be going.

A study made about six years ago by the Engineering Manpower Commission showed that only about 17 percent of the American population is endowed with the intellectual capacity and the qualities necessary for a career in one of the professions. Of these, half are women who seldom seek careers in the professions. The number of people, therefore, who are both intellectually able and available is only about 9 percent of the population. It would be unthinkable to expect all these people to become scientists and engineers. From this 9 percent must come also the people in other professions which are similar to science in the intellectual demands they make upon their practitioners. This 9 percent must furnish our doctors, our statesmen, our men of letters, our lawyers, and other professionally trained groups of people. Perhaps the most we can expect for science and engineering is about a quarter of this 9 percent, or some 2 to 2½ percent of our total population. About three million young people come of college age each year, and 2½ percent of this number comes to about 70,000 people. We are actually producing scientists, engineers,

and mathematicians at just about this rate. In other words, we are producing these people about as fast as we have any justification for expecting to produce them. The morale of this little analysis is that with a ceiling on the number of professionals that we can possibly squeeze out of our population, the increasing demands upon professions can be met only by upgrading the quality of the people we are turning out. The remainder of my talk will focus on some of the ways in which I think this upgrading may be brought about--ways for which I believe the foundations have already been laid.

When I look ahead a few years, what do I seem to see?

First: We shall have new ways of making the teaching of science and engineering more efficient and more effective than it now is.

Second: There will be progressivly less emphasis on the <u>facts</u> of science and more emphasis on the <u>nature</u> and <u>methods</u> of science as an intellectual and experimental discipline.

Third: Vocational and academic guidance will be better keyed in with the current real needs of society.

Fourth: There will be more frequent and meaningful contacts between teachers and the people in our professional scientific, industrial, and commercial communities.

I said first that I thought there were now developing some new ways of making the teaching of science and engineering more efficient. What did I mean by such an assertion? Let me give you an example. An engineering college student may spend a semester in a course in mechanical vibrations. The next year he may take a course in electrical a-c theory. He may follow it up with a course in acoustics, and perhaps with another one in optics. Actually he has been studying the same thing over and over again--wave behavior. He has been using the same differential equations, with electrical symbols in one course, where there were mechanical symbols in the course before. But the basic concepts which are common to wave behavior everywhere he has merely been studying, repetitiously, in a set of contexts which are only superficially, but not conceptually, different. How wasteful all this repetition is! The inefficiency of this kind of curricular structure, combined with the need for teaching more as human knowledge advances, is forcing some of our engineering colleges--so unnecessarily, I believe--to adopt a five-year curriculum.

It seems to me that many more opportunities of the same kind exist at both high school and college levels--opportunities for generalizing some of the many-faceted basic concepts of science and engineering in order to present them in a shorter time and, incidentally, to demonstrate better the universality of these concepts. Let me give you a few more examples:

<u>Example 1</u>: How many high school science teachers--or college engineering professors, for that matter--have recognized or presented to their students the idea that heat flow (in a thermal conductor between points of different temperature) is conceptually similar to laminar fluid flow in a tube under pressure and that both are conceptual analogues of Ohm's Law in electricity? In all these cases, whenever there is a flow of some kind, the magnitude of the flow is linearly dependent on the driving force producing the flow. Yet how

many students, having already mastered Ohm's Law, spend additional evenings trying to understand the diffusion equation in kinetic theory, where the flow is linearly proportional to the concentration gradient of the diffusing material?

Example 2: How many teachers have attempted to transmit to their students the insight that the multiplication of force, made possible by a mechanical advantage machine such as a lever or pulley system, may be the same thing conceptually as the multiplication of voltage by an electrical step-up transformer? Or that the resulting step-down of velocity in the mechanical system is analogous to the corresponding step-down of current in the electrical case?

Example 3: By the time a student is through with a high school physics course, he undoubtedly knows that the energy expended in a mechanical process is given by the product: force times distance. He also knows that the energy delivered in an electrical circuit is the product: potential difference times the charge transported. He may know, too, that the work done in the compressing of a gas is equal to the product: pressure times change in volume. He knows these things as isolated, unrelated facts. But how likely is he, without help from some really perceptive teacher, to bundle all these ideas up into a single earth-shatteringly beautiful generalization--the generalization that whenever you take an intensive quantity and multiply it by the conjugate extensive quantity, the product is always work?

Now do you begin to see the direction I'm suggesting? It is simply this: The more we can perceive and exploit similarities among things which are logically related, but which we would otherwise have to waste time teaching separately, the more efficient our teaching will become. In addition, the student himself will wind up with a much better organized set of more deeply penetrating insights. As the amount of knowledge which it is necessary to impart through teaching increases, we can prevent the educational process from becoming unrealistically long-drawn-out by exploiting such opportunities for association and generalization.

And I see on the horizon evidences that the possibilities for such exploitation are beginning to be realized and put into effect. Case Institute of Technology has been teaching an undenominational variety of engineering for several years. Other universities, Illinois at its Chicago branch, for example, are doing away with the traditional departmental structure and organizing their engineering curricula instead around major concepts. Here and there you find courses in generalized transport theory, generalized wave propagation, generalized systems engineering, each one cutting across several of the classical divisions of knowledge. All in all, to me, the prospects look good.

Now let's get on with the second point: The teaching of science and engineering will emphasize less and less mere information and will emphasize more and more the methods and approaches of science as an intellectual discipline. To elaborate, I believe that there is among the American people a terrible and dangerous misconception of what science really is. And I believe that this misconception has been generated and perpetuated by the way science has been taught.

What are some of the symptoms of this mass misunderstanding? Science seems to be confused everywhere with knowledge. Almost any and every array of facts is labeled "scientific." The greater the welter of information we can accumulate about the universe and everything that's in it, the more scientific we imagine ourselves to be. When the youngsters in the third grade of the local school begin taking nature study, the parents proudly imagine that their youngsters are starting science. High school science fairs are still loaded with leaf collections and model-building exhibits that more properly belong in hobby shows. The meaning of the word "science" has been stretched to include many activities not directly connected with the sciences. Universities, for instance, offer degrees in a curriculum called Library Science. Even the service station on the corner gets into the act by advertising a scientific tune-up for your car motor. The American people, by and large, are science happy about all sorts of things that are not science.

I don't believe that this widespread misunderstanding of science can be dissipated until some new emphases are brought to bear in high school and college teaching. Despite the fact that the word "education" derives from Latin words meaning to lead out, the present emphasis of science and engineering teaching seems to be on cramming in. "Here is an ever-increasing body of scientific information," the students seem to be told. "Learn it and you will be a scientist." No implication could possibly be further from the truth. The world's most knowledgeable person could at one and the same time be the world's most incompetent scientist. And our most outstanding scientists have not always been people who knew a great deal.

Let me at this point describe for you a few specific cases which may help you to see what's bothering me. They are cases which appear to illustrate the awful consequences of overemphasis on information at the expense of versatility and practical problem-solving ability. I once scandalized a group of high school physics teachers by asking them how many of their students could solve the following problem: "How fast would a satellite have to go to orbit the earth in a circular orbit at an altitude of 3000 miles?" The teachers looked at each other incredulously and then gave the following answer: "Oh, our students couldn't possibly do that problem. That would be a dirty trick." "Well, but why?" I asked. "Your kids know the laws of motion, don't they? And the law of gravity? And they certainly know all the simple algebra they need to do this problem. Why would it be a dirty trick?" The answer was: "Yes, we know, but you don't seem to understand. This isn't the kind of problem the kids are used to doing."

Maybe I expect more of kids than I should. But I couldn't help wondering what good those physics courses were really doing. Education is supposed to open doors--not put people into intellectual straitjackets.

Now let me tell you about the unhappy aftermath of this kind of conditioning. And this is the type of aftermath of which we, training directors, see a great many in industry. Any junior electrical engineering student could calculate for you the a-c driving voltage across a capacitor in a series resistance, inductance, capacitance circuit when you give him the magnitude of the a-c driving

voltage. But I once got my fingers terribly burned when I gave the same problem in sheep's clothing. I asked a group of electrical engineering graduates--graduates, mind you--to calculate the amplitude of the tidal fluctuation in Jamaica Bay after giving them the capacity of the bay and the equivalent inertia and resistance of the water in Jamaica Inlet, along with the tidal fluctuation in the ocean outside. Only three men in 24 solved the problem, and I received a discouraging storm of protest from many of the others. They were electrical engineers. What business had I to expect them to handle a problem like that?

I believe that by far the greatest value of any academic engineering or science exposure lies not in the facts which the students have to learn, but rather in the facility which they acquire in the application of methodical, analytical, disciplined, unshackled thinking. Information, of course, has to be part of the picture as a vehicle for the inculcation of these mental approaches, but it is sterile to employ the information primarily as an end in itself. To demonstrate this preoccupation with facts at the expense of things more important, let me ask you to furnish your own answers to the following questions about courses which you teach:

How many of your students, when they complete the courses you teach, have acquired a better idea of what science really is as a disciplined method? How many of them have been helped to think logically? How many of them learned something of the methodology of getting started on a new problem? How many of them have been taught how to design an experiment to get a valid answer to a question they haven't heard asked or answered before? How many have learned anything about the drawing of valid conclusions from a set of experimental data, and how many can tell the difference between a valid and an invalid conclusion? How many of them, instead of simply being turned loose in a laboratory with a lab manual telling them in detail what to do, have been really taught to figure out for themselves what they ought to be doing? How many of them even know the purpose of the experiment they performed yesterday afternoon? What effort was made to teach them to distinguish between fact, conjecture, and wishful thinking? How many of them have been taught to distinguish the significant from the trivial? How many of them have been provided with real lessons in objectivity?

If our young people aren't having experiences of these kinds, I say they aren't learning science or engineering: they're merely sponging up knowledge and slowly but surely turning into two-legged repositories of information.

Now let me admit before I leave this topic that I have been baiting you a bit in the interest of dramatizing the point. Teaching of the facts and fundamentals of what is known will always occupy a large portion of any science curriculum. Of course, it has to. But I do believe that science teaching in 1970 will embody a great deal more of the emphasis I have been talking about. And by then, perhaps, it won't seem so crucially important whether or not our youngsters learn the difference between a second-class and a third-class lever, or what the numerical value of the specific heat of brass is.

What makes me think we're making progress in this direction? For one thing, the new high school courses that have been put together--the PSSC physics course and the upcoming Harvard project course, the CBA and CHEM Study approaches in chemistry, and the BSCS project

in biology do a superb job in establishing physics, chemistry, and biology as observational and experimental sciences.

Also, from what I know of both high school and college level science courses, I see a trend toward more dependence on self-reliance and problem-solving ability. I see increasingly more exhibits in science fairs in which there is clear evidence of the application of the scientific method. Experiments are performed, data are produced and analyzed, and conclusions are drawn. The selected high school students who visit our company and the college boys to whom we offer summer employment do seem to be quite sharp, not merely in knowledge of subject, but also in the other attributes I've been talking about.

Now let's talk about guidance and guidance personnel, point number three. Northern New Jersey, where I come from, is a heavily industralized region. Business, commerce, and both light and heavy industry abound. The high schools in this area are fairly progressive in the way they furnish academic and vocational guidance services for their students. However, all the guidance personnel whom I know individually, altogether some dozen people, whom I regard as representative of the Northern New Jersey area, and possibly typical of many other areas as well, are people with liberal arts or teachers college backgrounds.

This mismatching between the orientation of the guidance personnel and the real needs of the scientific and technological economy is unfortunate. The college-bound students destined for professional careers in science, engineering, medicine, and the arts and letters are usually very well helped in the counseling they receive. However, the non-college-bound students, who will find subprofessional careers as draftsmen, machinists, and technicians are often sold short by their counselors, many of whom still believe that the proper way to prepare students for these careers is to put them in a terminal or vocationally oriented curriculum. The fact is that these students are just as much in need of academic quality training at the high school level as are the college bound.

Industry employs thousands of these subprofessional people every year, some directly from high school, others after one or two years of additional junior college or technical institute training. However, most companies employ, even in these categories, only people who clearly have the potential for growth, and these are the high school graduates whose intellectual equipment has been kept in active condition through exposure to academic quality courses in physics, chemistry, mathematics, and languages, including English. A youngster whose mathematics never got beyond shop arithmetic and whose science never got beyond a freshman course in general science, doesn't have enough to build on to make him look like a good training risk. And without further training his future in the company would not be very promising. There's one thing graphically arresting about a terminal high school program: it's so terribly terminal.

Well, what can you do about? At least two things. You can try to attract into guidance positions people who are in better contact with the facts of life in a technological society. And you can work with the people who are already in the guidance business to try to improve their own understanding of the real and present needs of this society.

Recognizing this unawareness on the part of high school guidance people, representatives of the New Jersey chapters of the various national engineering societies organized a few years ago a group called the Engineering Council for Student Guidance. The object of this is to work with educators and guidance personnel toward the end of interpreting to them the kind of educational preparation really needed by young people destined for both professional and subprofessional careers in science and engineering.

I should add that our contacts with these guidance specialists have always been delightful. We have found them to be as sincerely eager as we, in industry, are that their understanding of present-day educational needs in all areas be kept current.

Finally, regarding point number four, about the increasing relationship and contact between science teachers and science practitioners outside the field of education -- does anybody really doubt it? One sees evidence of the increasing nature of this relationship on every hand. People from industry are asked to talk to groups of students about career opportunities in science, engineering, and mathematics. They are invited to help judge science fairs. They are guest speakers at students' science seminars and at teachers' institutes and workshops. Teachers, professors, and industrial representatives have worked together in the development of the new physics, chemistry, and mathematics courses. Many industries have sound contacts with high schools and colleges in the part-time cooperative employment of students, and in the exchange employment of teachers and professors. Teachers as individuals and in groups often ask for an opportunity to consult with industrial people when curriculum and course content revision is being undertaken.

I believe that these evidences of increasing mutual regard and cooperation are as encouraging as they could possibly be. During the 1930's and '40's, human nature and inertia being what they are, educators were working in something of a vacuum, in partial isolation from the world they were supposed to be preparing younsters for. And members of the rest of the community, busy with their various preoccupations, were content to leave education almost entirely to the educators. This lack of contact between the two worlds was the subject of much concern by thoughtful people long before the sputniks started flying. The sputniks merely focused nation-wide attention onto this problem, and created an environment in which a great deal of progress has since been made, despite the witch-hunting and scapegoating which was inevitably a part of the picture.

I think it is very healthy that educators are no longer taking the position that education is exclusively their domain and that outsiders have no business even asking questions about it. Equally healthy is that the professional, industrial, and commercial community is no longer taking the position that it has no obligation to or responsibility for what goes on in the schools and colleges. These attitudes are old-fashioned and are destined for updating. The educational scene of 1970 will, I am sure, see a very fruitful expansion of the valuable cooperation already in progress between the schools and colleges and the other institutions of our society.

So much, then, for the elaboration of what appear to me to be four of the more significant present-day trends that will have their

impact upon the science education of the future. There are, of course, others. For example, I didn't mention at all the exciting new teaching aids and teaching aid techniques which have come into the picture during the last decade. During the coming few years such things as closed-circuit and wide-broadcast TV, lay helpers, team teaching, language labs, scrambled textbooks, and teaching machines will all doubtless come in for a lot of agressive huckstering and really purposeful evaluation. And I didn't mention, either, the whole new field of continuing education for adults which is now an assuming and expanding segment of our thinking and planning.

I can't remember any time in history when there has been as much ferment and movement toward change in science and engineering education as is going on right now, from grade school through graduate school. I like what I see, because in all the specific matters which I have mentioned, the present movement seems to be in the direction of improvement.

A PROSPECTUS FOR AN INTRODUCTORY SCIENCE COURSE

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There is evidence that despite the focusing of attention on science courses in the post-sputnik era, the general position of science as a subject has not improved in the schools. Excellent revisions of the introductory courses have been developed for the science major, and good courses in physics sans calculus have been developed for the humanities student, but apparently they are not the entire answer. Something is still lacking in the new courses from the point of view of the general student who is not planning to go on to do specialized work in science and engineering. The signs of this appear, for example, in a study of the career choices of the top stratum of high school seniors about to enter college during the years from 1937 to 1963, which showed a declining of interest in scientific research and a sharp decline of interest in engineering. The same study showed that such traditional professions as medicine and law were holding their own, while the humanities and social sciences were increasing in strength.

There is evidence also that the scientist occupies an ambiguous position in the general scale of social values. A recent study of the attitudes of college women by Beardsley and O'Dowd, indicates that those who would like to marry a doctor or a lawyer are thirteen times as numerous as those who would prefer a scientist husband. Another study of the attitudes of high school students, by Mead and Metraux, shows an even stronger antipathy, extending to active hostility. Dr. Mead's summary states: "The scientist is thought by high school students to neglect his body for his mind; he bores his wife and children and friends with incessant talk no one can understand and he forces his children to become scientists."

My own observation of the situation since I came to New York is that the bright students do generally come out of school with an antipathy toward science, except for the small minority of students who are planning to go on to careers in the field. The general student does not seem to get the satisfaction from introductory science courses that he receives from learning the elements of music or art, or other subjects in which he may not be specializing. I think it is clear that while we do a superb job of training our students for professional work in science at the high school level and in college, we are failing to reach the great majority of students who are not science-oriented.

There is a tendency in the scientific community to feel that this indifference is only the product of the very severe demands which science makes on the intellect; and that the general public and the general student are unwilling, or unable, to make the effort required to master the basic substance of science. I do not think this is true for most students. I think that certain attitudes in the scientific community, which have, in turn, affected the way the sciences are taught, are partly or largely responsible.

First, scientists have permitted, and occasionally encouraged, a public image of science to develop as an impersonal and dehumanized field of work, unintelligible and inaccessible to all but a gifted few. This stereotype portrays the scientist as a man who starts with a premise of established fact, proceeds by formal reasoning, and arrives in this way at an incontestable conclusion. It represents the scientist as a logically perfect but alien being, dealing in facts and truths, a man who works like a machine. This image is false because a scientist goes about his business in the same manner as everyone else, relying heavily on subjective and intuitive judgments. However, when he has reached a significant result, he covers up his traces and replaces his intuitive reasoning by formal discussion designed to convince his colleagues. These traditional methods of presentation in the scientific literature, which conceal the intuitive element in scientific discovery, serve to alienate the layman.

Second, scientists are generally uninterested in teaching, and the more so the lower the level of the course; whereas most teachers will testify that the lower the age group of the students, the harder and more interesting the task of teaching becomes.

Now to come to the principal point: The introductory science courses do not clearly explain the broad intellectual contributions which science has made to the Western world, although these contributions are of the greatest interest to the general student, more so than the mastery of techniques which the professional student requires. The science student only becomes aware of these broader implications of the scientific revolution when he has reached an advanced level of training. The student who is not oriented toward science is not likely to receive them at all, although it is he who most badly needs this broad point of view. He must have it in order to understand science as one of the forces which shape his society and to be an informed and effective citizen.

Most existing introductory courses, however, concentrate on certain specifics which have a distinguished tradition in science teaching but which are no longer meaningful or important to the student in contemporary urban society. Physics courses, for example, are usually organized around the teaching of the laws which govern the workings of mechanical devices, the flow of electricity through wires, the tracing of rays of light through systems of lenses, the operation of heat engines, and a smattering of nuclear and atomic physics. These facts are required by electricians, plumbers, and nuclear reactor engineers; they might also be useful to people who lived on the frontier, or who live today in rural areas. But they are not necessary for the student in an urban society which services most of his needs with elaborate technical organizations, for the man who does not plan to install the electric wiring in his house, or for the man who does not plan to go on to professional study in science or engineering.

As an illustration of the fact that certain developments in science of the most profound general interest cannot be taught within the framework of any single one of the traditional science courses, I should like to tell a story which draws on major concepts and research advances in four separate disciplines of science--physics, astronomy, the earth sciences, and biology. The relevant developments in physics

and astronomy concern the formation of the stars and planets. An abundance of evidence indicates that space is filled with clouds of hydrogen, which is the simplest and most abundant atom in the universe. The atoms of hydrogen in space are occasionally drawn together by gravity to form a condensation. As the condensation develops, it heats up, until at a critical temperature of 10 million degrees, the coulomb barriers between the atoms are penetrated, and the nuclear force takes over and fuses the protons together to form helium nuclei. This is the first step in a series of reactions in which all the elements of the periodic table are synthesized. It is also the way in which a hydrogen bomb works, although we have never succeeded in reproducing the reaction under controlled conditions on earth.

It is now thought that in the case of our own solar system this all happened 4.5 to 4.7 billion years ago. But available astrophysical evidence suggests that the birth of stars is frequently accompanied by the formation of planets, just as our own solar system, and that solar systems probably are a commonplace feature of the universe. In fact, planets have already been detected in motion about nearby stars. In 1963 the Sproul Observatory of Swarthmore College announced that it had detected a planet with approximately the mass of Jupiter revolving about Barnard's star six light years away, which is only a stone's throw from the sun in the scale of stellar distances.

Our galaxy contains 100 billion stars, and 10 billion other galaxies, each containing a comparable number of stars to ours, are within the range of the 200-inch telescope on Mount Palomar. In the multitude of planets accompanying these stars, there may be some which resemble the earth in size and distance from their own suns. Let the stars harboring such planets be relatively few in number; let them be as rare as one in a million; no matter, the number of earth-like planets will still be 100,000 in our galaxy alone.

Can we maintain our belief in the uniqueness of life on the planet earth in the face of these numbers? We can on the astronomical evidence alone, because all planets but ours could be dead bodies of rock. But the latest advances of the biologists suggest that this is not the case.

First, they have discovered that all known living forms on the face of the earth are constructed out of two basic building blocks--the amino acids and the nucleotides--just as the physicist has shown that all matter is constructed out of three building blocks--the neutron, proton, and electron. Twenty distinct kinds of amino acids and four kinds of nucleotides provide the foundation for all kinds of life on earth. Within the cell the amino acids are linked into long chains of proteins with several hundred amino acids in each chain. The proteins divide into one type which make up the structural elements of living organisms--the walls of the cell, hair, muscles; and another type, the enzymes--they accelerate the assembly of small molecules into larger ones within the cell. The nucleotides are also joined together within the cell to form long strands of deoxyribonucleic acid, or DNA for short. DNA is the molecular storehouse of genetic information. The order in which the nucleotides are arranged along the DNA molecule determines which proteins will be assembled within the cell. While the basic amino acids are the same in all forms of life, the

proteins into which they are joined, through the action of DNA, differ from one species to another within the cells of one organism. The DNA contains specific instructions for linking the proteins that characterize that particular creature. However, the basic set of 20 amino acids and 4 nucleotides is the same for all living forms on the planet earth, whether bacterium, mollusk, or man.

Second, the critical amino acids and nucleotides have been manufactured in the laboratory out of the gases which filled the atmosphere of the earth at the beginning of its history. In one experiment by Miller, these gases--ammonia, methane, water vapor, and hydrogen--were mixed and circulated through an electric discharge. After a week the water contained several types of amino acids.

Amino acids and nucleotides could have been formed in the atmosphere in just this way four billion years ago, by the discharge of lightning. Gradually they would drain out of the atmosphere into the primitive oceans, building up a nutrient broth of continuously increasing strength. With the passage of time, chance collisions in the broth would link some of the basic elements into more complex molecules which lie on the boundary between inanimate and living matter.

According to this story, life will appear spontaneously in a favorable planetary environment if vast amounts of time are provided. How much time is needed? Studies of the fossil record suggest one or two billion years--a period which will be available on any planet whose star resembles our own sun.

This mechanistic description of the origin of life seems scarcely credible. If we watched a sterile broth of organic molecules for 50 years, we could not expect life to arise from it. But a billion years is a long time. We cannot be sure it did not happen this way. Accepting the theory, what is the likelihood that advanced societies have appeared on any of these life-bearing planets? Four or five billion years were required for evolution to our stage of development, and we have about four billion years left before the demise of the sun. Some societies, on stars which formed before ours, must have passed the level of our technology billions of years ago.

Where are all these other people? Physical contact with societies based on other stars is an unlikely prospect in the foreseeable future, for the stars are very thinly scattered in the sky, the average distance between them being 20 trillion miles, or about 4 light years. We have no feasible way of raising spacecraft to the speed required for interstellar travel at this time.

But although direct physical contact appears to be unlikely, interstellar communication is within the realm of possibility. The threshold of radio communication, which we crossed only 60 years ago, may have been reached on other planets thousands or millions of years earlier. We must expect, therefore, that others who have capabilities for radio communication far in advance of ours, are already listening and will hear us first. Only in the last few decades have we begun to emit enough radio and television noise to attract their attention. Sometime, perhaps soon, we may expect a message.

This is one example of the way in which a pedagogically valuable

story can be developed by bringing the methods and results of several distinct disciplines to bear on one central problem of science. There are others. I began by remarking that each of the traditional disciplines is an independent stream of research to the scientist working in the field and to the science teacher, but the fact is that all are concerned with a small number of fundamental problems of a broad interest. I have the feeling that there is a growing tendency for cross-fertilization in science education, a breaking of the barriers that have characterized the structure of science teaching.

These thoughts lead me to propose a course which may be a useful experimental approach for providing for the needs of the general student. This course will invert the usual order of science courses in high schools by starting with basic physics and building up to biology. In the proposed curriculum, each of the major scientific disciplines is introduced, its basic substance is presented, and its contribution to the development of our general understanding of the physical world is explained. The intent is to give the student an understanding of the substance of many fields of science in a context in which they are seen to illuminate the central questions of man's physical existence, rather than existing by themselves as separate, compartmentalized fields of inquiry.

I suggest as the central problems: the identification of the basic particles and forces which govern natural events; the role played by these forces in the structure of matter in the small and in the large; the interplay of forces involved in the formation of stars and galaxies; finally, the origin of planets, such as the earth, around the stars; the evolution of planets and their atmospheres; and the origin and chemical foundations of life.

It is important to emphasize that this reorganization of the curriculum will not talk <u>about</u> science; it will present the <u>substance</u> of science--the old wines, but in a new bottle. It will begin with quantitative descriptions of the neutron, proton, and electron as the fundamental particles out of which all matter in the universe is constructed. It will describe the quantitative properties of the basic natural forces--gravity, electromagnetism, and the nuclear forces; the laws of motion; and the interplay of particles and forces, through these laws, in the birth of stars and galaxies; the synthesis of elements; then the condensation of planets around stars, the circumstances in the history of our planet which appear to have made it suitable for the evolution of living organisms; and finally, an introduction to the latest developments in molecular biology, and an account of experiments by which the chemical elements of the living cell have been created in the laboratory out of molecules which are believed to have existed in the atmospheres and oceans of the primitive earth.

At this point I stop because I am a physicist. But in a recent meeting of a committee on junior high school science education, under the auspices of the AAAS Commission on Science Education, there were people present of a different background, who found this program reflected in the teaching of physics and astronomy and the briefest elements of molecular biology, something about which they already felt strongly in the biological sciences and the sciences of man. In these fields, too, they feel there is a convergence of streams of inquiry in, for example, neurophysiology and psychology, and a growing tendency to unification, which provides an opportunity to present the student with a view of science as a coherent account of the physical and biological

environment of man, rather than a compartmentalized group of parallel studies.

Out of these conversations developed the proposal that the unified presentation of science be extended beyond the chemical foundations of biology, into a second year, in which one would continue with cell formation, the development of multicellular organisms, and the evolution of the higher animals, with more details on molecular genetics; with the reasoning, in terms of the physical and chemical response of the organism to its environment, which makes it possible for us to follow the fossil record, not only as taxonomy, but with the understanding which a student can only have if he builds on the unified picture of physics and chemistry which he has acquired in the previous year. The course might continue with a discussion of the nervous system, the processes of learning, memory, and communication; and then, possibly, in a third year, we would come to the sciences of man--psychology, anthropology, and sociology.

It is a long way from the neutron, proton, and electron to the biochemical foundations of learning, communication, and psychology. But this is, in fact, the most important contribution which science has made--that in the most modern developments one can trace a single connected path, without any major gaps, from the elementary particles of physics to the complexity of the biological sciences.

EDUCATION OR TRAINING:

THE HUMANIZATION OR DOMESTICATION OF MAN

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I am convinced that the course of human development depends upon the practitioners and teachers of science as upon no other single group of individuals in our day. And this is true, not so much because science has become an obviously vital societal technique that must be exploited as a matter of survival in a fiercely competitive world, as it is for much deeper, more basic reasons. As of the present moment, all of mankind is completely and inextricably involved in the most profound and the most portentious of a long and spectacular succession of great human revolutions--the mastery of fire, the invention of agriculture, the discovery of metal fabrication, the development of urbanization, the conquest of controllable sources of mechanical power with the consequent emergence of industrialization, and now the burgeoning impact of science. The Scientific Revolution is sweeping on in an ever-swelling tide and every inhabitant of our world, however remote he may seem to be from science itself, is being borne into a new and uncharted future on its flood of material, of intellectual, and yes, of spiritual accomplishments. The nature of that future can now be seen only as through a glass, darkly.

It is particularly appropriate to quote from Darwin's discourse here because the man and his book exemplify the very essence of the Scientific Revolution; the ability to think logically and objectively as well as to remember accurately, to understand as well as to know, to synthesize as well as to analyze, to dwell in the world of the abstract with familiarity as well as to inhabit the familiar earth with effectiveness. It is precisely with these elements of the Scientific Revolution and with their potential impact on human history that my remarks will be concerned.

To me, the consideration of man's status eons hence and of our part in determining that status would be a far more comfortable business if some recognizable image of Darwin himself were logically acceptable as symbolizing the common human condition at that distant date rather than the somber portrayal of that condition which his essay presents. However, wishful thinking is undoubtedly man's most deadly disease, and truth and comfort can never be assumed to be compatible companions. While I disagree on some minor details of the picture he paints--largely due to new knowledge unavailable to him when he wrote--the disagreement is in detail only and I must concur that the odds are almost overwhelming that when that contemplated future becomes the existing present, his description will indeed still stand, a prophecy fulfilled.

However, I would make one important reservation to this endorsement. I am convinced that it lies within man's capabilities to pursue an alternative course leading to a quite different eventual status on the dawn of that millionth year. And this despite the fact man is a wild animal, indeed primarily because he is wild. For

wildness does not connote some necessary lack, either in the number and quality of the wild one's acquired skills or in the degree to which his innate intelligence has been developed, in fact, quite the contrary might be the case. The essence of man's wildness does not lie in some imperfection in his development, but rather it stems from the absence of any continuing, universally exercisable, and purposive source of absolute domination over his behavior, and from the freedom this bestows upon him to exercise his inherent urge for experiment. It is Darwin's thesis that such absolute domination over the whole of mankind by any individual, or even by some specialized ruling segment thereof, is highly improbable at any given time and totally impossible to maintain for more than an ephemeral moment in the fast span of human existence. Darwin points out that such a ruler, or the peer in such a ruling clan, would himself still be wild--that is, he would be subject to no external authority which could compel his obedience. Moreover, he would also have to be supremely successful in his wildness, a true human genius, or he would promptly lose his absolute authority. However, if by some means he should succeed in establishing his absolute domination, he could then be successful in actually domesticating his subjects. This would be possible since, as the result of the isolation which mastery brings, he would be in a position to apply to the accomplishment of his purposes that total objectivity in observation and judgment upon which sound scientific achievement depends.

Thus, as repugnant as it would be to me, a society of demi-hominal cows, each yielding the milk of superlatively expert human performance in his prescribed occupation, and each securely chewing an ample and perfectly balanced cud of physical, mental, and perhaps even a certain modicum of spiritual largesse in return for the services he performs, would seem to constitute a feasible future for the human race. Its accomplishment would appear to lack only the essential Great Man required to bring it about. Naive belief that it would not happen provides no shield against its occurrence. Even we, for whom freedom forms the keystone in the arch of our societal structure, erode its substance, continually chipping away the demanding granite of individual initiative and responsibility and filling in the cracks with ever thicker layers of the less personally taxing mortar of collective security.

If we who have known freedom will trade it bit by ever-so-infinitesimal bit for security, what of the overwhelming hordes of men who have never experienced freedom, to whom it is but the most vague of visions--the dimly imagined antithesis of their accepted servitude? Here the soil for domestication is fertile and readily tillable. Here there is no loss of a divine right held, only the clearly visible personal gains that a more perfect state of domestication would yield. Here the values placed on an individual human life are not so transcendent that the elimination of the less fit and the control of procreation--factors upon which the achievement of full domestication must depend--could not eventually be achieved under the guise of the "common good." And the potency of the resultant society might well be such that it could overwhelm the remainder of mankind either reducing the alien wild men to its own domesticated state or eliminating the nonconforming residues entirely.

It is Darwin's thesis that such an ultimate domestication of man will not, and indeed cannot, occur--certainly as long as the

span of human life remains finite. The reason lies in the fact that of absolute necessity the rulers of such a domesticated society must not only be wild men but wild men of superlative genius in order to make it work. And one such ruler is not enough, nor is a continuous succession of some several such super-men adequate to achieve such a goal. True domestication is a long, slow, selective process. It requires an unending succession of generations to achieve its purposes--perhaps a thousand years would find it firmly on its way, and ten thousand might see it entrenched. Even then, were the succession of wild rulers to falter in its continuing genius, not only would the effectiveness of the domestication achieved wane, but with that decline the absoluteness of the domination exercised would also diminish and eventually vanish; with the disappearance of that absolute authority the state of domestication would swiftly and totally disintegrate.

Domestication, to whatever extent it exists, not only requires submission to authority but engenders an essentially total dependence upon that authority for its continuance. The processes of selection that maintain and improve it--the preservation of this one as superior and the elimation of that as unfit--cannot be self administered, but the objectivity upon which the effectiveness of the requisite selection depends cannot be self achieved. The performance of the individual task, superlative as it may be in its execution, awaits assignment by established authority. The "what to do" has long ceased to be the prerogative of the doer; indeed, it has become beyond his ability to determine.

Thus, the establishment of a domesticated society not only requires the Great Man for its inception, it demands an unbroken succession of Great Men for its continuance. And this the Great Man cannot achieve. Just as the domesticated human specimen is incapable of successfully continuing his domesticated state by self-imposed rule because of the impossibility of his achieving objective judgment of himself, so the wild ruler can bring only subjective judgment to his understanding of his own strengths and weaknesses. He cannot know objectively the sources of his success and lacking that objective knowledge he cannot insure the succession of others with abilities like his own that would be requisite in establishing and maintaining a domesticated human society.

Human history has had its example of Great Men who have gone far toward initiating such a social order. There are a few instances in which there have been a brief succession of such individuals. However, history would seem to bear out Darwin's basic contention that no wild man, however brilliant, can so fully fathom the wells of his own wildness that he can select or develop a successor with any certainty that such successor will indeed possess the qualities essential for successful continuation of his own career. Thus, if subjective judgment is indeed always fallible and that, due to the very fact of its subjectivity, man will indubitably remain an essentially wild animal, his wildness subject alone to the compulsions of his culture.

Up to this point I find it difficult to take exception to Darwin's reasoning. Certainly vastly more must be known and understood about the functioning of the human mind before subjective judgments, certainly those concerned with the self, even approach in reliability the standards we have now attained in arriving at objective judgments. Since the crux of his argument rests on this point, the probability

that his conclusions in this regard are indeed wholly valid would appear to be high. However, at the next point in the development of his thesis I would like to interject the reservation I mentioned earlier, for however minimal its probability of realization it would seem to offer the only presently foreseeable course down which the ever-continuing stream of human generations can flow other than that depicted by Darwin.

Darwin assumes that, like all wild animals, man will follow Malthusian law and thus will always procreate to the limit set by the currently available level of sustenance. This limit is reached when the deaths from starvation in the ever-existent fringe of marginal subsistents holds the birth rate in balance. This is a very real limit and is guaranteed by the finiteness of our natural resources and is enhanced in its sobering significance by their ever-dwindling magnitude. While I happen to be convinced that the total energy supply available to man is many orders of magnitude greater than it appeared to be to Darwin, writing in 1852, this constitutes only a minor detail in the sum of the argument.

It is still true that even today certain of our resources in materials crucial to our present cultural pattern would be inadequate to provide our standard of living to every person now alive, even if the total earthly store of these substances were to be immediately extracted and put to use. The hope of developing substitute materials provides but a partial and probably at that an impermanent answer. The population explosion that is now pursuing its largely unrecognized and unchecked course will be just as deadly in its outcome as would the recognized and deeply dreaded nuclear war. Moreover, the human travail it will induce will, if anything, be even more agonizing, for starvation constitutes a slow, inexorable and clearly observable decline to ultimate death. There is no medical procedure that can permanently alleviate the torments of hunger, let alone provide a cure for its ravages, and the fact that it is likely to be shared by the most concerned observer as well as by the observed brings no anodyne to either.

A truly Malthusian world is far from being a pleasant thing to contemplate even as an abstract concept; it is far less pleasant when one must recognize that it is to such an unenviable but inescapable state that we, by our present behavior, are consigning the future generations of man. Bowed before his conscience in the silence of self-judgment, man can no longer halt at the question "Am I my brother's keeper?"; he now must face that ever harsher query "Am I trustee for the welfare of man a million years hence?"

Now it is not sufficient for single segments of mankind to control their populations in the hope of maintaining and perchance of even improving their own standards of living. No matter how strong their societies may be, they will eventually be overwhelmed by those with uncontrolled numbers. The very level of civilization which effective population control promotes renders them vulnerable. The Malthusian ethic can bide no temporization with dire necessity. The niceties of codes of civilized behavior constitute luxuries that cannot be tolerated. Only machination and raw force provide instruments capable of seizing that expanded lebensraum which alone can alleviate the immediate exigencies of the Malthusian ills. Our sense of decency cringes at the report that the Chinese leadership has said that China could

well afford to lose two hundred million of its citizens in order to expand its boundaries. But even if the reports should be true, we should not be startled for this is but simple realism in an overpopulated society, and China can certainly see at least the fringes of the Malthusian cloak hanging over the bamboo curtain if the cloak itself has not indeed already begun to spread over the Chinese realm.

The practice of the Malthusian ethic must follow close on the heels of recognition of the existence of the Malthusian state, and inherent in that ethic must be a total disregard for the individual when the welfare of the individual is in conflict with the welfare of the society of which he is an infinitesimal part. Machination may sensibly take the lead, but if its success is faltering raw force must follow. To believe that any principles of civilized restraint or that any fear of mass destruction would serve as deterrents to conflict in the face of critical population pressures is naive. Stark need writes its own rules of action and mass destruction would be but a passing incident in the history of an uncontrollably proliferating people. Even failure to achieve the desired expansion would not end the struggle. Unless the mass destruction which led to the failure were pushed ruthlessly to total annihilation--a practice prohibited by the code of civilization that is an inevitable attribute of a society capable of achieving population control--the whole process would be repeated again and again down the centuries.

Eventually, a time would come when the society of controlled numbers, perhaps lulled into an overconfident estimate of its own strength by the very societal advances its population control had made possible, would be overwhelmed by the society of uncontrolled numbers. Restrained by no taboos, the latter would totally eliminate the former, occupying its lands and exploiting its resources. Uncontrolled fecundity will always have another day and will always return to the conflict its proliferation eventually makes necessary; controlled procreation, in the long term, inevitably leads to its own annihilation for it can only fail once. This simply means that if population control is to be achieved, it has to be achieved on a universal basis, for any lesser attainment would constitute no attainment at all in the millionth year end result.

I should like to make it quite clear that I have mentioned China as an example only because she appears to have travelled farther down the Malthusian trail than any other great society. I am convinced that as our population continues to expand in uncontrolled fashion over the next century or so, our position then will differ not one iota from that of the Chinese now. It is not a matter either of racial or of cultural history; it is solely a matter of human survival, and any human society when faced with the Malthusian asymptote will be driven inexorably to the eventual display of this same behavior.

Glancing over the globe and contemplating the enormity of man's cultural diversity, one can readily understand Darwin's confidence that universal population control, like a true world government for whose establishment such a demonstrated control would be prerequisite, is so fantastically improbable that it could be ruled out summarily. Granting the enormity of the odds against its achievement, I still believe that not only is man's control of his numbers achievable, but that with the realization of this goal, a whole coordinate set of

cultural objectives would be attained. I believe this for two reasons. First, I am convinced that as our understanding of cultural dynamics grows, it will become evident that the course of cultural development can indeed be guided by purposive intent and concomitantly purposeful action. True, the cultural processes involved are admittedly slow since the cultural inertias involved are truly enormous, and the cultural forces that can be exerted are finite. The time scale sweeps on into the future with the human generation as its inescapable unit of measurement. Nevertheless, I am convinced that the laws of dynamics are valid in this cultural system and that a purposive force continuously applied to human culture can produce a purposed change in the structure of that culture. The acceleration produced may indeed be small, for the force that can be marshalled and maintained may be feeble. However, if the force is finite and continuous, however small, the rate of change increases and in the fullness of time the volitionally intended change will be achieved. If this be heresy, so be it.

The practical problem, of course, is that of establishing and maintaining the necessary purposive force. This brings me to my second reason for believing that universal population control is an achievable cultural objective.

A characteristic of Darwin's theory of large numbers is the existence of statistical fluctuations. While the magnitude of the average deviation becomes smaller as the numbers become larger, there always remains a finite probability of a very large fluctuation. The probability of such an occurrence happening at all is indeed small, and the probability that it should occur at a time and in a situation such that interactions due to its chance existence would permanently alter the course of events is vastly smaller. Nevertheless, I am convinced that the Scientific Revolution constitutes precisely such an incident in man's cultural evolution. I believe that this massive cultural fluctuation, if purposively exploited, can result in the initiation and unremitting continuation of a cultural force of such relatively extreme magnitude that, in a comparatively short time as evolutionary changes go, the condition of man could change from that of an existence within an increasingly inflexible, culture-controlled state of pseudo-domestication, largely dominated by a scale of materialistic values, to that of life within a burgeoning state of humanization in which a steadily expanding and diversifying scale of intellectual values, unique to man, would assume an ever-increasing cultural ascendancy.

Now I realize full well that statements of personal belief, no matter how intriguing they may appear to be at the moment, rarely ever engender lasting conviction in the persons to whom they are directed. Only to the extent that these individuals can be persuaded to tread the path of observation and argument for themselves, following it through to its ultimate look-out point after exploring the by-paths as they go, can they be expected to appreciate the view it commands and to fix that view in their own beings with the vividness and permanence that constitute belief. In the time that remains I cannot lead you, step by step, along the entire trail, nor should I, for once you have set foot upon it I feel sure that you will explore it to the end for yourselves and with much greater personal profit. However, I would like to point out briefly some of the salient features

you will meet along the way, for these might serve as guides to aid your progress.

The first feature to be examined is human culture itself, its nature, its role in human society and, in particular, the way in which it evolves. If you have not read Professor L. A. White's book on the Evolution of Culture, doing so would provide a fine starting point; if you have, re-reading would still be rewarding.

All too many of us indulge in loose talk about man's "free will." Listen to any one of a vast class of standard commencement speeches and the implication is clear that, if man would just "will" to be good, all earthly woes would disappear; ergo, all the graduate need do is to dedicate himself to the task of getting man to "will" the good and the world would be saved. The worst of it is that many of these speakers naively, but nonetheless passionately believe precisely what they say. To them the ills of human society are obviously due to the perversity of men and they do not comprehend that the perversity they abjure springs from sources far deeper than individual caprice.

Man is free to exercise his "will" and the normal man does so with conviction. What is so frequently not realized, or is ignored, is that what that expressed "will" will be has long since been foreordained by the culture which has inexorably shaped that individual's attitudes and patterns of thought and action and which thus determines almost definitely his every decision. Only when his culture fails him in some wholly novel situation and provides no pat formula or established feeling to fix his decision is he at last driven to thinking for himself. And for the vast majority of mankind the agonies of any attempt to use reasoned thought are likened to the convulsions of death. Even the members of that fragment of a society whose daily occupation depends on the skilled use of rational thinking find that a highly developed ability to reason provides something less than an omnipotent arm with which to combat the deepseated, but often illogical, emotional attitudes deriving from the cultural heritage to which they are subject.

For any society as an entity, its culture is dominant and essentially absolute in its compulsive power. This is as it must be for the successful survival of man has been as dependent on the overriding authority of his culture as it has upon the equally absolute determinism of the human genes that control the uniform flow of successive, essentially identical human generations. The insect transmits his successful survival experience by genetically rooted instincts; man transmits his corresponding experience through the mechanism of his culture. Survival effectiveness in both instances has depended on the fact that both mechanisms have provided essentially complete control over the continuing behavior of the species concerned. Both have insured--in quite different ways, to be sure--that change from behavioral patterns of proven survival value would occur only under the inexorable compulsions of alterations in those environmental conditions under which the previous survival experience was valid. Human culture is thus an inertial entity of almost incredible magnitude; the almost universal lack of objective recognition of its existence and of its role as dictator of personal conduct simply enhances the potency of its domination.

It should be pointed out that despite the absolute nature of culture's domination over man, cultural control can lead at most to a state of pseudo-domestication as Darwin points out. Culture is the reverse side of the same coin of which man's inherent wild nature is the obverse. The growth of culture is entirely an accretional process. Culture serves a purpose, but is not of itself purposive. Thus, domestication in its true sense is not an attainable objective within any cultural framework, for the achievement of such a state demands not only continuing absolute authority but clear and unwavering purpose as well. However, insofar as the domesticated state can be characterized by unquestioning submission to authority, the extent of domestication achieved by any culture is measurable by the degree of absolutism it exercises in its domination. Blind acceptance, conscious or unconscious, of cultural compulsion is indicative of an advanced, domesticated condition; trenchant question of cultural dogma is the emblem of freedom, the insignia of a true state of humanization.

The second leg of the trail to an understanding of the situation, as I believe it to be, requires an exploration of the means by which culture can establish such an autocratic sway over the behavior of the people from whom it springs. Here no more than a suggestive direction is necessary for you are all familiar with the terrain. Culture establishes its control through the process of everlasting, compulsive training enforced and continually reinforced by the whole arsenal of social pressures ranging from high approbation through noncommittal acceptance and clear disapproval to total ostracism. The more effective the training a given culture provides, the more autocratic the control it is enabled to exercise; the more complete its dominance, the more effective is the training it can achieve. The system is autocatalytic and constantly tends toward a state of total behavioral control; only the ineradicable, inherent wildness of the human animal itself prevents a culture from achieving a state of utterly stagnant conformity.

Training is the tool of cultural inculcation, for the essence of training lies in its requirement for its own acceptance as the ultimate in authority. It transmits to the learning present what has been judged best in manual and intellectual skills, in knowledge and explanation, and in custom and belief from the winnowed harvest of all past experience. The fact of the winnowing is lost from sight in the emphasis on the transcendent merit of the product. The trainer's cry is ever, "This is the way. In this situation this is what to do and this is the way to do it. Memorize and practice and perfection will be yours." This is the handbook way of life. It places but a minimal demand on the full complement of human intellectual capabilities. Kinesthetic and rote memory aided by indoctrinated mental routines for carrying out standard analytical techniques suffice. The question "But why?" is anathema; all too frequently the answer to "Why?" is unknown to the questioned, and the very fact of its asking constitutes heresy.

Now training with all of its authoritarian features is absolutely essential as a basis for all effective human performance. However, it should provide a beginning only; it should never constitute the end of human education. Training is indeed but the handmaiden of education. The greater the extent to which training dominates the human educational process, the more absolutely the culture it transmits

controls the society in which it is embodied and the less flexible it becomes in the face of environmental change. A human society can readily achieve its own extinction by yielding its heritage of active wildness for the passive comforts of conformance, by renouncing its struggle for full humanization in an abject acceptance of domestication.

But if human behavior is indeed dominated by culture and culture by its control of training is self perpetuating, is it in fact possible for man to have any effect at all on the shaping of his own destiny? Exploration of this question constitutes the third segment of the proposed journey toward verification of my belief. It seems indubitably true, as Professor White maintains, that a socio-cultural system is indeed a closed system as a physicist would define it. The more one ponders the situation, the more valid and inescapable this conclusion seems to be. Thus, just as no man can literally lift himself by his bootstraps, no cultural system can of itself and within itself change its cultural level and direction. Only external interactions occurring at the boundaries between the socio-cultural system itself and its real and abstract environments can produce such changes. These interactions may be scalar as in the flow of energy and materials between the system and its real environment, or they may be vectorial as in the acquisition of new knowledge from objective observation of the real environment or in the development of new understandings by logical association of factors recognized in the abstract environment.

Now, the scalar factors are concerned with the sustenance of the socio-cultural system alone and are thus mostly concerned with its size; it is the vectorial interactions that provide the external forces that are capable of changing the system's cultural level and direction. These vectorial interactions occur only in individual human minds, and only then if the minds are free from authoritarian cultural compulsions at least within the areas of observation and contemplation. Moreover, such vectorial interations can only be achieved in minds that can pursue synthetic thought successfully, as well as test the validity of the syntheses achieved analytically. It is a matter of creative thought to learn to recognize the previously unperceived, to know the unknown, and to understand the ununderstood. These are the attributes of scientific thought, of true research in any field, and they are uniquely human capabilities. It is the development of these faculties that constitutes humanization. This is the function of true education.

Now, although a closed system can never lift itself by its bootstraps, to the extent that it can sustain internal displacements and exert internal torques upon itself, it can change its aspect to its environment. The cat dropped upsidedown lands on its feet much to its benefit. A socio-cultural system can likewise of its own volition shift its aspect with respect to its environment and, by so doing, volitionally influence its own destiny. The Scientific Revolution is a reflection of this process in operation.

The increased interest in science aroused by its material accomplishments is bringing an ever-increasing fraction of human effort to bear in this region of intellectual exploration. This is increasing the magnitude of the vectorial interaction between the socio-cultural

system and its dual environments and consequently increasing the forces, both material and abstract, acting on the system. The resulting culture is still accretional and will remain so, for no man or group of men possesses the omniscience and omnipotence required to coerce the course of events, the less so the more closely the culture approaches the state of full humanization. But culture does become more and more flexible as the process continues, for as true education permeates the population more and more completely, reason at last begins to have its opportunity to exercise its influence in a massive way on the accretional process and thus on the content of the pervading culture. This will in no sense decrease the magnitude of the influence exerted by culture on human behavior, for training must of necessity precede education, and cultural attitudes are probably firmly fixed by training before formal education can begin. But the attitudes now contemplate education as requisite for societal acceptance, and man can move toward humanization out of the slough of his pseudo-domestication. In such a culture, population control becomes truly possible and the inevitability of the Malthusian nightmare recedes from the human scene.

But can this internal reorientation from a misplaced trust in training to a demand for true education be maintained until it becomes rooted in all segments of human culture? As we have seen, it must be universal in its inclusiveness, or it will fail. Here begins the last climb to the promised lookout.

The cultural change from domestication to humanization can be universally achieved if the present course of the Scientific Revolution can be maintained and if its implications are realized and utilized by that powerful subculture, the world of the school. Science shares with religion certain basic elements, elements that in man's past history have made religion one of the most profound sources of those vectorial interactions that determine the course of cultural change. In the first place, both science and religion are based on unshakeable, even fanatic faith. The faith of scientists that the procedures of scientific thought will lead to the truth is one with the faith of the devout that conformance with religious law will lead to salvation. The dedication that science induces in the creative scientist is of the same stuff as the dedication of the true believer. Even the missionary spirit is shared. And in addition, science is not a faith without works. Its material accomplishments stand as a challenge to all, its spiritual satisfactions need be experienced but once to enthrall the novice and claim his eternal allegiance.

The appeal of science is observable today in all corners of the world and among all classes of people. The demand for that education needed to open the doors to active participation in or even to full appreciation of science is universal. The ancient call of "Come over into Macedonia and help us" is heard from all quarters of the globe. If we understand the meaning of true education and are willing to do our part in spreading the word, all mankind can achieve true education, whether the indivual concerned is a scientist or not, and in that achievement man will have accomplished his own humanization.

This, then, is the vision, this the goal. You, the practitioners and teachers of science are the real disciples of the Scientific Revolution. Paradoxical as it may seem, if man is to achieve that

humanization which lies latent in his being, rather than to descend slowly to an earthly Malthusian hell, the burden of the accomplishment falls upon your shoulders. It is you that must go out into all the world and teach the gospel of the powers of scientific thought and of the values of intellectual satisfactions. And the time is now while that cultural fluctuation formed from the substance of the Scientific Revolution is still expanding explosively throughout all nations. Science alone speaks a universal language; science alone is concerned with universally recognized truth; science alone commands a universal faith and by its works exercises a universal appeal; science alone comprises in its body of research and teaching scientists a truly universal socio-cultural system that, precisely because of its attributes as a cultural entity, is capable of exercising the continuous, long-term vectorial interactions requisite for the achievement of permanent change in the socio-cultural system as an all-inclusive whole.

Have we, the practitioners and teachers of science, the wit, the resolve, and the unfailing resources of faith in science and of enthusiasm in its pursuance that are needed to weld these elements into a single instrument of societal action, and cultural force that can reshape the whole course of man's cultural evolution? I believe we have. So let us be about it remembering that this task can never be accomplished by any impersonal, mechanical process no matter how expert the technique employed, nor how exemplary the formulary invoked. Only as we succeed in igniting the spark of intellectual consciousness within the deepest recesses of youth's being and in fanning that wisp of flame into an enduring blaze of total intellectual commitment can our objective be achieved.

Training can and indeed must be taught, but education can never be impressed, it can only spring up from within, kindled by our own inner fire. If we transmit our knowledge and our skills alone, mankind will move inexorably down the road to an ultimate Malthusian pseudo-domestication. Only as we ourselves believe in man's essential humanity and give of our own consuming intellectual fervor can universal education be achieved and man move along that rugged but exciting trail of humanization toward a truly human destiny.

PART II. DISCUSSION OF PROBLEM AREAS

EDUCATING FOR SCIENTIFIC LITERACY

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I do not view my assignment as being the affirmative speaker in a debate entitled "Is a Scientifically Literate Public Desirable?" Speakers and writers far more eloquent than I have spoken of the pervasiveness of science into every facet of our culture. A scientifically literate public isn't even just desirable, it is essential. The only topics still open to discussion are two: First, what are the goals and purposes of science education? Second, how do we go about attaining them?

In one sense there actually is little argument left on the first of these topics. A fairly general consensus has been reached by the mathematicians, physical scientists, biological scientists, and earth scientists as to what underlying principles are basic to an understanding of their respective disciplines. I think one of the most important accomplishments of the various curriculum studies sponsored by the National Science Foundation is that scientists were caused to pause and take a long, piercing look at what is really significant in science education. Furthermore, there has developed a remarkable agreement among all scientists as to how science should be taught: as open-ended discovery with implacable inquiry and boundless skepticism.

One of the best of countless statements I have seen regarding the purposes and objectives of science education was made by William Kesson on behalf of the AAAS Commission on Science Education in the Journal of Research in Science Teaching, Volume 2, 1964. This statement summarizes with great clarity the Commission's views on the teaching of science as a framework for development of elementary school science materials. In its concluding paragraph is the following sentence,

> "The child can understand only what he has been prepared to understand, the teacher can teach only what he knows, and the meeting of the prepared child with skillful teacher is an unforgettable encounter for both."

Professor Kesson did not emphasize this sentence in any way, but to me it succinctly points up the single, most formidable barrier to achieving the goal of a modern world of scientifically literate people. "The teacher can teach only what he knows."

Now I shall appear to digress from the point, but not really.

Let us take a look at the baccalaureate class of 1965. Most of these young people would have been born in 1944. Of all children born that year, 74 percent made it to the sixth grade, 53 percent lasted to the eleventh grade, 47 percent graduated from high school, 24 percent entered college, 14 percent will receive their bachelor's degree, and about 3 percent may earn the doctorate.

To look at this another way. At this point in time, if we consider all Americans 25 years or older, 10 percent have fewer than six

years of schooling, 60 percent have not reached the eleventh grade, only 7 percent have four or more years of college work. At the polls the vote of a college graduate can be cancelled by the vote of a person unable to get beyond the fifth grade. One conclusion is inescapable. Teaching for scientific literacy must begin in the first grade. Every child must have acquired at least the rudiments of scientific literacy in the first five years of his schooling. The sophisticated, exciting, and challenging materials by BSCS, CHEMS, CBA, PSSC, and others cannot affect more than 60 percent of our school population.

Going along with these depressing statistics is another educational trend which is relevant. At least at my college, I am told, there has been a change over the past few years in numbers of students preparing for the elementary teaching credential. I understand that formerly about two-thirds of credential candidates were at the elementary level. Now the proportion of elementary credential candidates is about one-third. This trend, if indeed it is general as I suspect, somehow must be reversed.

There are two things that can and should be done, in my opinion, to assure effective teaching for scientific literacy beginning the very first school year. First, the profession of elementary school teaching must be given the status, dignity, community respect, and financial reward it deserves. The first-grade teacher must be given a niche in society comparable or superior to the town's banker, businessman, newspaper publisher, physician, and in these days, the operator of the family pool parlor. This is difficult to accomplish for the very scientific illiteracy we seek to eliminate is the cause of the present inferior status of the elementary school teacher.

The second step we can take will be equally difficult. I claim no authorship in the proposal I am about to outline. Bentley Glass sketched it broadly five years ago. It received little publicity and far too little discussion. As a part of his duties, each teacher should be required to spend every fifth year of his career in college. This year should be devoted to study of substantive science courses. His full salary should be paid as well as all costs of his refresher education. Why every fifth year? Many scientists have estimated that the half-life of scientific knowledge in the fast growing fields is about five years. Let us not confuse this "back to the ivory tower" movement with a sabbatical program. They are not the same. I submit that the year in study is an absolute prerequisite to effective and up-to-date teaching in the following four years.

Should this proposal be adopted it would be expensive. Salary budgets would jump a minimum of 25 percent, for it would require five teachers for every four now on the payroll. Actually, the figure would be closer to 50 percent. Salaries would have to be raised generally to attract more competent people into the teaching profession. Inevitably the program would require federal subsidy with all the overtones of federal control. I am not overly concerned. There are controls of sorts now in the institute programs, fellowship programs, and educational facilities programs, if one looks hard enough.

Educating for scientific literacy will be expensive whether this or any other program is instituted. But it will be far less expensive than any alternative to a scientifically literate population.

GENERAL EDUCATION IN THE PHYSICAL SCIENCES

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As I thought about the rather different situations and experience which have given the phrase "general education" the specific meanings it has to the various members of this group--even though all of us have common interests--I was worried that meaningful communication on this topic may be difficult. For example, my own training is in physics, and the large majority of my students have been science majors. Surely, my concept of general education courses must be vastly different from that of one of you who has trained in, say, biology and who is a professional in the preservice training of elementary school teachers. The term "general education" must carry a different image at Harvard than it does at a small teachers college in some remote part of the country. Therefore, to clarify my own viewpoint, I turned to Webster and chose this combination as expressing very closely my own preconceived notions: "General education is the discipline of mind or character through study or instruction, not limited to a precise import or application." The key phrase here is "not limited to a precise application."

To me, this strongly suggests two guidelines for teaching general courses in science. The first is that general education students of science should not be mixed in the classroom with students who do plan to apply their scientific training to their specific goal of becoming scientists. I occasionally hear my research-oriented colleagues express the view that we teach science the way it should be taught in our introductory courses designed for science majors, and others who wish to learn some science should take those same courses. I believe this is nonsense! The two groups of students have had entirely different experiences from early ages onward. One group has tinkered with mechanical gadgets and been intrigued by mathematical puzzles. The other has found more satisfaction studying literature or the fine arts, or trying to understand the social relationships among human beings. I do not see how at the college level one can adequately serve the needs of both groups in a common course.

Again, I remind you that my chosen definition says that general education should be limited to study not designed for precise application, and I believe this also says we should not design science courses exclusively for prospective teachers. Undergraduate college students rarely know exactly what they want to do, nor is it clear how they could choose wisely before sampling several different disciplines in more depth than one can at the high school level. Courses designed for the broad category of nonscience majors can serve future teachers at the same time that they provide general scientific literacy for a variety of other lay citizens.

Some of you may complain that these two points are contradictory--that, on the one hand, I want to isolate scientists but, on the

other, I refuse to distinguish between teachers and nonteachers. To this I reply simply that sorting out persons who need and want extensive science training from those who do not is a coarse-grain process necessary for effective science education. Singling out elementary teachers from the large group of nonscientists and grouping them in special science courses is unnecessary and tends to result in inferior science education for teachers--a group who can ill afford to be badly informed in an important area of knowledge which they must someday interpret to children. Thus, my first major point is that elementary teachers should learn science along with all other kinds of nonscience majors, but they should not be thrown into introductory courses designed for science-oriented students.

The second major point I wish to make involves the manner in which science courses for nonscience majors are created and taught. One may correctly say that courses for nonscience majors have existed for years and, thus, wonder why there is so much concern today about the reform of science courses. There is a simple answer to this which I would like to state quite bluntly. Until recently research scientists showed no interest in teacher training and cared little about the scientific literacy of the general population. They engaged in the search for knowledge and taught in such a manner as to perpetuate their own kind. Now it has become clear that pure research requires broad support from government and, hence, from the people. The people, in turn, recognize that science plays a big part in their lives, and they demand sufficient understanding of it to be able to form intelligent opinions on important issues. Thus, the scientist has been driven to a concern for how the layman learns science, and he finds that what is being taught in the name of science often fails to convey a real understanding of the problems he is studying in his laboratory or the methods by which he seeks answers. How could it be otherwise when for years there has been so little communication between the teachers of the nonscience majors and the top research scientists?

At long last, scientists are now writing materials for science courses designed especially for nonscience majors and contributing to the teaching of these courses. I would like to urge strongly that this attitude of concern be encouraged and that cooperation be fostered wherever possible between the scientists at the frontiers of their fields and professional educators who have a realistic understanding of the over-all educational needs of preservice teachers. Only by uniting the knowledge and skills of both groups can we break into the cycle in which scientifically illiterate elementary teachers mold attitudes in children which cause them to resist careful observation of physical phenomena and precise mathematical analysis whenever opportunities for such activities occur.

My third and final point is a rather specific plea to reverse a trend I see developing at institutions which offer general education physical science courses. Many science teachers, discouraged by the questionable educational value of traditional laboratory exercises and harassed by heavy teaching loads, shortage of space, and lack of adequate funds to purchase modern apparatus, are abandoning laboratory entirely in courses for nonscience majors. I believe this policy is extremely unwise. It is not primarily a knowledge of scientific facts we wish our students to learn. Rather, we wish to transmit to them an appreciation of the processes of inquiry, observation, abstraction,

generalization, analysis, and prediction by which scientists organize man's understanding of nature. Since the entire chain is anchored in the phenomena it attempts to interpret, it is difficult to see how a program which fails to provide the student with an opportunity to stimulate and satisfy his own curiosity by direct observation could convey a realistic impression of the scientific enterprise. For teachers, a familiarity with apparatus is especially essential. How can we expect an elementary teacher to perform science demonstrations confidently for a class if he or she has never been exposed to controlled experimentation as a technique for studying science?

It is true that our laboratories have not always had the effects on our students which we desire. Somehow we have failed to have an atmosphere of inquiry in our laboratories. Instead, they are frequently overcrowded with students, understaffed with instructors, and poorly supplied with equipment. Students are given a recipe which, when followed without question, leads to verification of known facts. Such situations present challenging problems which must be met with determination, clever ideas, and more financial assistance. They call for greater effort by each of us, not capitulation.

Let me close by urging each of you to support, in whatever ways you can, efforts to create laboratory physical science courses which properly reflect the scope and content of modern science and the utility of its procedures. The time is right for reform in general education science courses; interest has been kindled in many quarters. The importance of the job of science teaching to the future of mankind is now unquestionable. Changes are under way--don't be left behind.

SUMMARY OF DISCUSSION GROUPS

Problems of Science in General Education

Nature and Structure of Science

Because of the nature of the methodology and intellectual processes employed by scientists in the discovery of new knowledge, science is unique among the curricular areas. The procedures consist of the formulation of theories which guide probes into the unknown. Certain assumptions or postulates, deductions or inferences can be drawn. Such deductions or inferences can be subjected to experimental or observational tests from which certain conclusions based upon evidence yielded by these tests can be formulated. A theory is not proved or disproved in this process, but rather it is strengthened or weakened by the findings. With continued testing a theory may become well established or it may have to be modified or superseded by a better one. Theories are regarded as tentative, not absolute.

Nature of the Course

All aspects of the science course, including curricular development, the instructional methods used, the classroom atmosphere, the nature of the laboratory studies, and the evaluation procedures used, should emanate and derive their validity from the course objectives. These course objectives, in turn, should be expressed in behavioral terms and should concern themselves with the implementation of the kinds of activities that constitute science, as described in the preceding paragraph.

The general education course should not be regarded as a service course or as a foundational course to the other sciences. It should not be a course about science, it should be a course in science. It should be exploratory in nature and should involve the student in scientific activity in the laboratory. Lecture, films, discussion, and evaluation activities should all help give direction to the course. Although there is no traditional body of standard content as such which must be "covered" in such a course, students who have not yet declared a major should be afforded the opportunity to become acquainted with the field of science, not just the first course in one area of science.

A high quality general education course can profitably be taken by all students, including science majors. It gives them an overview of the field of science and some insights into the nature and structure of science that they often do not get in the beginning specialized course, where the major preoccupation is "covering" the subject matter. However, if all students are required to take the general education science course, much flexibility should be provided in the form of honors sections (enriched), opportunity for acceleration or waiver by examination, special sections for slower learners and/or repeaters who have previously failed the course, as well as for those with poor backgrounds in science.

Objectives

1. The principal goal of general education science courses is the presentation, development, and emphasis of a few unifying concepts of science.

2. Such courses should include insight into the nature of investigations in science and some appreciation of the philosophy of science.
3. Such courses should prepare students so that they can and will want to continue an interest in science as demonstrated, for example, by their reading with comprehension newspaper and magazine articles on science.

Role of the Laboratory

The laboratory is definitely essential for any real understanding of science. Laboratory here is defined as actual student participation in discovery--an experience which includes some experimentation and independent investigation, and which fosters appreciation of science as inquiry, not just routine practice with techniques or with repetition of known results.

A nonlecture science course would be enjoyable and effective, but would not be practical for the numbers of students involved on most campuses. Interdisciplinary approaches can be effective in meeting the objectives of learning laboratory procedures and, at the same time, giving adequate coverage. There is definite need for fresh approaches to traditional ideas, particularly approaches that are adaptable to modern classes growing in size.

Role of Mathematics

Most teachers feel that it is possible to begin teaching a course in general education science with students knowing mathematics at the level of arithmetic. But students will not remain at this level for very long. The course will be supplemented with a growing knowledge of mathematics, including some algebra and geometry, as the inquiry into science develops. Inquiry will develop more rapidly if the students are conversant with algebra and geometry before beginning the science course. Much of the fear of science courses now expressed by students would be allayed if they had overcome their fear of mathematics before beginning the science courses.

Staffing and Administration

If the general science courses (or series of courses) is to flourish and become distinctive, there must be a genuine commitment to it by the department chairman, the dean, and the president of the institution. Ideally, the course should not be under the jurisdiction of any other science department in the institution. In large institutions, it might well be a separate department, with its own head who reports directly to the dean, just as the heads of botany, zoology, chemistry, and physics do. The dean, in turn, should accord equal status to the individuals who teach the general education science course (or courses) as is accorded to those who teach the specialized science courses. Specifically, this status will be reflected in the following:

1. Teaching loads will be adjusted so as to afford some research opportunity. Research and writing will be encouraged.

2. Opportunities for promotion to full professor on the basis of meritorious work over a substantial period of time will be

afforded. A career with tenure in this area would be possible.

3. Opportunities for attending conventions will be on a par with those granted to staff members in the specialized sciences.

4. The general education science staff will have its own space and equipment. They will not continually have to borrow from other departments.

5. Time will be made available for staff members to create their own curricular materials.

The faculty for the general education science course should teach the course because they have a desire to teach it, not because they are assigned to teach it. Ideally, faculty for the general education science course should be hired in the open market on the basis of a compelling interest in and deep commitment to the philosophy of general education and because their own educational background especially qualifies them to develop and teach such a course.

While the general education science course can be operated efficiently so as to give a stimulating science experience to large numbers of students at a reasonable cost, this should not be a primary objective of the course. Ideally, the textual and laboratory materials and study aids should be custom made, i.e., written by the staff members to fit the course as conceived and offered in their own institution. It will, of course, be advantageous to exchange ideas with others who are engaged in highly successful general education science programs elsewhere. But to lift the curriculum in toto from one institution to another, without modification or adaptation, is usually highly unsatisfactory.

Evaluation

The outcomes of instruction in the general education science course should be evaluated by a final examination of high quality to serve as a uniform measuring instrument for all sections. To prepare an examination of high quality, one should begin during the first week of the semester or term to create questions or items over that week's work and continue the procedure, week by week, filing questions in a folder for later refinement and editing. Near the end of the term, a few items that tie together several major related ideas can be constructed.

Conclusion

A general education science course

1. Is academically sound
2. Is both interesting and intellectually challenging
3. Emphasizes inquiry in laboratory work
4. Provides for individual differences
5. Provides for adequate evaluation
6. Provides for breadth as well as depth of content

Course instructors

1. Are interested in teaching the course

2. Are qualified to teach the course
3. Have freedom to plan the course
4. Plan the evaluation of the course
5. Receive recognition and respect for their work

In brief, a student who has successfully completed the course will have a lasting interest in science, will use wisdom in making necessary decisions concerning scientific matters, and will continue to learn about science through reading newspaper and magazine articles of a scientific nature. These may appear to be unattainable goals, but they must be achieved if we hope to develop scientifically literate citizens in our society.

GENERAL EDUCATION AND THE PREPARATION OF ELEMENTARY TEACHERS

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My remarks shall be confined primarily to the difficulties of offering good college science courses to prospective elementary school teachers. It would be quite presumptuous for me to stand before this group as an expert on elementary school education. I have had no direct experience in this area. However, during my year of working on the staff of the Commission on College Physics, I have become convinced that the preservice training of teachers is one of the most important--and most difficult--tasks a college or university scientist can undertake. Thus if interest qualifies me to speak on this subject, I am certainly well qualified; however, I have much to learn.

First, let me review with you what I know about the undergraduate science requirements of elementary education majors. There is a table in "Physics Manpower and Educational Statistics 1962,"[2] which gives the distribution function of the number of schools from among 50 state universities included in the study versus the number of semester hours required in biology, physical science, and natural science. (The table includes chemistry, geology, and physics, but the number of schools requiring courses with these names is negligible.) The details of the table are interesting, but I will give you only the averages: biology--3.6 semester hours; physical science--2.7; natural science--4.3; total--10.6. If one adds to this the average of 1.8 semester hours listed for mathematics, the total is still only 12.4. I would like to urge that minimum requirements in this important area of knowledge should be considerably greater than this. The NASDTEC-AAAS Guidelines for Science and Mathematics in the Preparation of Elementary School Teachers[3] wisely specifies certain skills the teacher should possess and topics with which he or she should be familiar, rather than the hours of college credit one should accumulate. I think you would all agree, however, that few students will reach the level of scientific literacy which Guidelines recommends by taking 12 semester hours of science and math.

I am also distressed by the lack of balance and integration which I have observed in several university teacher-training programs. For one thing, entirely too little time is devoted to mathematics, both for its own sake and for the support it lends to science. Second, I

[2] Available from American Institute of Physics, 335 East 45th Street, New York, New York 10017

[3] NASDTEC-AAAS Studies, 1515 Massachusetts Avenue, N. W., Washington, D. C. 20005. AAAS Misc. Publ. No. 63-7

regret that the physical sciences are frequently slighted in favor of the biological sciences. I believe this situation is worse than the difference between 3.6 and 2.7 suggests, since I suspect much of what is taught under the title of natural science is closer to biology than to physics. Finally, it seems a pity that at many institutions where a balanced program is required, little effort is made to establish relationships between the various science and mathematics courses. Apparently one effort to solve this problem has been the adoption of natural science courses, where all sciences are taught by one teacher. This plan sacrifices too much in order to achieve integration. Surely few teachers can adequately represent the points of view of many disciplines at a level appropriate to bright college students.

I would like to propose a science and mathematics program for prospective elementary school teachers. If this does nothing but stimulate discussion, I will be satisfied; undoubtedly many of you will be able to tell me why it is unrealistic. The program would consist of one course in each of the student's four undergraduate years. The courses in order--and the order is important--are mathematics, physical science, biological science, and methods of teaching science and mathematics. The total program would occupy between one-fifth and one-quarter of the student's undergraduate preparation--I don't see how one can justify less, even though there are heavy demands from other subject areas, as well as professional requirements. In addition, it should be understood that each of these courses would be created specifically to meet the needs of prospective elementary school teachers and with full consideration of the nature of the other courses in the sequence. This is not to say that the first three courses would not be suitable for certain groups of liberal arts majors--I am convinced they could be--but I do insist that mixing these students with groups that have greatly different goals--such as science majors--contributes much to the unfortunate image under which science courses labor at many institutions.

Let me now turn my attention to another problem in offering good preservice science courses for elementary school teachers, namely staffing. At the large universities, the situation differs from one institution to another. Some schools of education, finding no suitable courses offered by the science departments, teach science themselves. They would be the first to insist that this situation is undesirable. At many schools the education majors are not separated from the liberal arts college for the first two years and thus must satisfy the arts college underclass requirements. These requirements may read well, but in practice this policy has tended to drive education majors away from the chemistry and physics departments, where teacher training has rarely been accepted as a responsibility, toward whatever nonquantitative courses will fill the bill. Where courses specifically designed for prospective teachers are offered by science departments, they are frequently assigned to the least able teacher or are accepted as an undesirable chore for one or two semesters by someone who will do nothing to dispel the pupils' fear of and distaste for science.

Fortunately, during the last few years some scientists have become concerned about this situation. Many now recognize that careless preservice training of teachers propagates disastrously to large numbers of elementary school students who later reach high school, college, and their adult life uninformed about science and often antagonistic to it. Some institutions are taking positive strides toward securing the

continuing, throughtful involvement of competent scientists in teaching science to prospective teachers. The University of Maryland has hired a recent PhD graduate in physics from the University of Michigan to a half-time appointment in the School of Education and half-time in the Department of Physics. He will have responsibility to work with the educators who teach science methods courses and with scientists in other departments to develop programs for prospective teachers. Other schools are adopting similar plans. I believe changes in staffing policies which will permit greater cooperation between qualified scientists who are interested in improving teacher training should be strongly encouraged.

At smaller colleges the staffing problems are somewhat different. Cooperation is less of a problem, since departments are quite small and physically close together, but in its place lack of time looms as a serious factor. The teaching loads are frequently so heavy and enrollment in introductory courses so large that the science teacher can do little more than meet his classes and grade his papers. Institutions of higher learning are slowly beginning to realize that the creative development of course materials and the organization of curricula are as demanding of time and talent as other kinds of research. Let us hope that as curriculum reform gains respectability among professional scientists, institutions will find the resources to reward imaginative and dedicated contributors with smaller teaching loads and larger salaries than has been common in the past.

Finally, I wish to examine with you the question of teaching materials. I can speak only for physics and physical science courses, but I find the large majority of texts, laboratory manuals, films, and other teaching aids designed for use by classes of nonscience majors rather unimaginative. Many authors seem to despair that sincere, intellectual involvement with the concepts of science is possible for these students and instead offer surveys <u>about</u> science. In some cases, I am told, these courses are offered without laboratory--a sure sign that the students are not expected to <u>do</u> science.

There certainly do exist very competent treatments of physics among the many introductory texts, but very few that were written with an understanding of the typical backgrounds of preservice teachers or of the specific problems they will encounter when they enter the elementary school classroom to teach one of the modern science units. Even when a suitable text can be found, the search for materials is not over, since a text by itself does not provide a broad enough variety of experiences for the student. One needs to discover the proper mix of problems, laboratory exercises, films, and supplementary reading to enrich and make more meaningful the verbal discussions and deductive arguments of the text.

The individual teacher rarely has the time to develop his own materials, and may even find it difficult to locate or piece together the proper components for a science course for nonscience majors. This leads to the suggestion that groups of scientists undertake the creation of integrated sets of materials specifically designed to serve the needs of prospective elementary school teachers, or perhaps a wider range of nonscience majors. This kind of cooperative endeavor would be especially well suited to the development of interdisciplinary courses, a goal which I believe is applauded by all but is surprisingly difficult to

implement. The Commission on College Physics and the Advisory Council on College Chemistry have been attempting to initiate development of materials for a physical science course. Reports of early conferences directed toward this end are available from the CCP office.[4] I particularly recommend that you read "Less May be More," a talk given by Philip Morrison at one of these conferences, published in the June 1964 issue of the American Journal of Physics.

I would like to report to you that our efforts to stimulate the organization of course development projects were not in vain. Two institutions, Rensselaer Polytechnic Institute and the University of Texas, have become centers where groups of scientists are planning working sessions to produce new materials. How soon one can expect useful output from these efforts depends in part on how successful the leaders are in securing financial support and the services of appropriate personnel. In any case, we cannot expect the output of any one group to serve the needs of every institution, since students, faculties, and facilities vary widely throughout the country. We can hope, however, that the spread of concern about teacher training, of which these projects are one manifestation, will ultimately lead to a richer variety of materials from which each college science teacher can choose.

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SCIENCE FOR ELEMENTARY TEACHERS
AND GENERAL EDUCATION

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I have taken my assignment to be the outlining of problem areas in the science preparation of elementary teachers and in science for general education. For two reasons I shall give short shrift to the latter. First, Dr. Jastrow's remarks should be sufficient to provoke a considerable amount of discussion. Second, I see many of the same problems affecting both areas.

Problems are not lacking when one considers what the science preparation of elementary teachers should be. Where to begin in talking about them is, in fact, a bit bewildering. One overreaching problem, however, seems to provide a context in which to view others. It is this: We are not really very certain about what the place of science instruction in the elementary school program should be, or even <u>can be</u>, and this puts a very serious limitation on our thinking about what science experience is appropriate in the preparation of elementary teachers. We are really just now beginning to probe seriously into the area of how young children learn the ideas of science. As a group, we keep asking ourselves questions such as "What should be the common preparation in science for all elementary teachers?" when at best the answers we can produce now can be only some sort of stopgap until we know more about children and how they learn science, and until we find ways of implementing this knowledge in action.

This is not meant to imply that there is no constructive activity aimed at providing the needed knowledge. There is. In places like Newton, Massachusetts; Webster Groves, Missouri; Urbana, Illinois; Berkeley, California; Geneva, Switzerland; and for that matter right here in Pittsburgh, are happening what one of our colleagues in mathematics has called "probes and thrusts." Many people today are asking questions of the "What will happen if we try to . . .?" variety. For example, such a question might involve whether Ohm's Law can be taught in a quantitative fashion to fourth-graders with some meaningful result.

Another sort of probing is illustrated by some research being carried on at Cornell which attempts to analyze concepts deemed appropriate for teaching at the elementary school level by breaking them down into structural units and then assessing whether children are capable of, to use Piaget's term, "internalizing" the units without which the teaching of the concept is just so much wheel-spinning. An example of this is the need for the child to be able to understand the idea of conservation of volume as a part of understanding density.

The answers to questions of the types just mentioned provide information about what <u>can</u> be done. But even as we gain this knowledge, we still face the problem of deciding whether or not what can be done at a given level actually <u>should</u> be done. The impact of the increase in our understanding upon the program for elementary teachers and the need for making intelligent decisions will be tremendous.

With that, I am tempted to stop, having completed my task of cutting off a big enough bite for all of us to chew. However, the day when an answer or answers to the big question are found is rather far off and we have to live with the realities of the present in the meantime. With this as a backdrop, at any rate, we ask ourselves what to do with, to, for, or about the elementary school teacher-to-be.

With little risk of argument in this group, it can be postulated that science has a place in the elementary school, beginning rather early and continuing toward some goals which are a part of a general school program, without attempting at this point to define what that place is eventually likely to be. This seems to demand some form of exposure to science for all elementary teachers, which, as we undoubtedly all know, has not been the case for a substantial proportion of elementary teachers up to this time. For example, I have had in recent years the experience of facing classes of inservice teachers in which a large majority could not use a protractor to any useful extent or graph simple data.

We cannot, however, reject out-of-hand those whose preparation is less than what we might desire. We must somehow provide in our planning for taking them as they are and bringing them to a point where they have some grasp of the process of science.

That there is some hopeful change in the tendency for prospective elementary teachers to shy away from college science courses is suggested by the findings of a study recently complete at Cornell. Among these findings was a positive relationship between the amount of college level science taken and the recency of the teacher's preparation. In case this gives rise to too much optimism, however, let it be noted that some 40 percent of the sample of nearly two thousand teachers had six hours or less of science in their college careers, with about half of that 40 percent having zero contact with science courses.

Let us look also at what science courses these teachers had taken. Therein lies a second problem. Some 40 percent of the teachers in this rather substantial sample had had some type of general biology course. The numbers indicating that they had had some physical science or earth science course were considerably smaller, with chemistry and geology running a poor second and third to biology in frequency. And, of course, there is a certain amount of overlap.

I do not intend here to quibble over the content or conscientiousness or honesty with which those courses were taught. Rather, they probably weren't the <u>most appropriate</u> contact with science for those elementary teachers to have had during the few hours devoted to science in their training. One is compelled to ask what the exposure to a typical one-year general chemistry course is likely to provide for a potential third-grade teacher. Separately and individually, such courses very likely left the elementary teacher with some facts, comparatively isolated in the compartments of a fragmented picture of science. Little wonder that a typical description of the elementary science program in a given school runs something like, "We <u>do</u> Smith, Jones, and Brown," (whatever <u>do</u> means). The problem remains: "How can we best overcome the fragmentation that has so often been the lot of the prospective elementary teacher?"

Rather intriguing is Dr. Jastrow's proposal for a "fused" science course for general education. It merits consideration as a format for a minimum science preparation for elementary teachers.

Another problem closely related to the nature of the courses is that of who is to teach them. Some question must be raised about the appropriateness of the course being taught by a professor of physics or chemistry who quite possibly has not seen the inside of an elementary classroom in many years. This does not imply that the science course should be taught by an experienced elementary teacher or a professor of elementary education; it suggests only that the instructor should have some valid idea of what his students are likely to be expected to do with what he presents to them. He should be aware of the seeming immunity of young children to that which appears to be irresistible reason or logic to adults. It would seem that here is a natural spot for a teaching team, including a team-operated laboratory.

In summary, there are serious questions demanding research: What science experience is appropriate in the preparation of elementary teachers? What form and content should it take? Who should teach it? The science teaching community has a great challenge, both in seeking answers to these questions and, in the meantime, handling an important segment of our college population.

SCIENCE EDUCATION FOR ELEMENTARY TEACHERS

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One might first ask the question, "What is expected of an elementary school teacher who has taken science? What do you expect a teacher to do after he has taken science that he could not do before he took it? The public expects him to teach science, and it is the responsibility of educators and scientists to see that he is prepared to do it.

What kinds of science courses are most suitable for preparing elementary teachers? What sort of criteria should be used in evaluating them? No matter what the curricula and no matter what the criteria, eventually one might reach the conclusion that, after the pre-teacher's education in science, he should be different than he was before. He should be able to react to certain situations in a way that he didn't before. He should be able to do certain things that he couldn't before. If these statements sound like behavioral objectives, this is by design and not by accident.

One of the hardest jobs of any teacher at any level is convincing a student that he has the power within himself to learn something on his own. This is a behavior that can be observed. To be able to increase the independence of students to think and learn on their own is the most worthwhile skill that can be possessed by any teacher. Too much teaching has been aimed at producing dependence of the student on the teacher. It is nice to have pupils around the desk asking questions, but too often the questions are "How do I get started?" "How do I continue?" "What did I find out?" "What does it mean?" Such dependency does not lead to independent learning.

If such behaviors as independent thought and investigative skills can be taught, there may be some hierarchy of levels of behavior, each of which is dependent upon those previously acquired. If this is true, it might be possible to arrange the behaviors in a sequential fashion and teach them in a systematic way, using a reasonable science curriculum as the vehicle for the task. However, there is little evidence that these possibilities are used by science departments in stating objectives for their courses.

How often does a science department state objectives like: At the end of this course the student will be able to define a set of similar objects in terms of their similarities, or the student will be able to reclassify a set of objects in another context so that the classification is operational for another purpose. How often do students have the opportunity to study carefully data they have gathered and organized and to infer and predict from their observations without being under pressure to come up with the correct answer by the end of the laboratory period? How often is the primary purpose of the laboratory exercise no deeper or no more stimulating than the requirement of committing something to memory that need not be studied again until the night before the test? If we expect prospective teachers to believe that science is more than a series of generalizations in a book, routine laboratory demonstrations, and boring exercises, we must teach it in a very different way.

The time is long past when we can afford to offer three or four unrelated, descriptive courses in which the material studied in one of them is ignored in the next. We must overcome the inertia that is engendered by ignoring the importance of creating and adhering to a sequence. Each course must depend upon previous ones. If objectives are behavioral and these behaviors can be arranged in a hierarchy, then each course can contribute to the next, both by reinforcing that which was previously learned and by encouraging the student to achieve greater competency.

If teachers are to teach investigation to their pupils, they must be taught in the same way. The American Association for the Advancement of Science is currently testing an experimental curriculum called "Science--A Process Approach."[5] Processes such as observing, communicating, inferring, predicting, using numbers, and classifying have been behaviorally defined and arranged in a hierarchy of increasing difficulty, so that processes which depend upon others are listed later in the sequence.

Preparing our elementary teachers without using a comprehensive sequence of processes based on behavioral objectives will deny them the tools they will need when they begin to teach. Such a lack of sequence, regardless of the curriculum, would prevent them from obtaining maximum effectiveness from what is offered. This is like ignoring all previous knowledge every new day because one does not see how it may be used. College instructors have only three or four semesters in which to teach science to prospective elementary teachers. They sell themselves terribly short if they deny the existence of science courses other than the one they teach.

In conclusion, may I suggest the following:

1. That science teaching, especially for pre-teachers, be sequential
2. That the objectives be stated in behavioral terms, and that these behaviors form the basis for a sequence
3. That processes such as those being tested by the AAAS be considered in their relationship to these behavioral objectives
4. That those departments now teaching college science courses for prospective elementary teachers continue to teach them, rather than having some new department or division set up for that purpose
5. That learning be measured by assessing behavioral competencies in the processes of science

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[5] AAAS Commission on Science Education, 1515 Massachusetts Avenue, N. W., Washington, D. C. 20005

SUMMARY OF DISCUSSION GROUPS

The Science Preparation of Elementary Teachers

Nature of the Problem

The problem of planning science courses for preparing elementary teachers is not different from that of planning courses for general education. However, the problem may be more critical because elementary teachers are expected to lay the foundations of a science education for all children--those who will become scientists and technicians as well as those who will study the humanities, citizens who will elect the officials of our government, and the officeholders themselves who must make decisions affecting the future of our nation.

Much of the fear and aversion to science that is shown by many college students, including prospective elementary teachers, may possibly be traced to negative reactions resulting from earlier science courses or from poorly designed college science courses. It is quite apparent that many of the science courses provided for nonscience majors and prospective elementary teachers fail to meet even minimum standards of the generally stated objectives for such courses. The growing importance of science and technology in our society makes it imperative to close the gap that exists between theory and practice of science teaching for preparing elementary teachers, as well as for general education.

Responsibilities of Colleges and Universities

Each institution must develop its own philosophy relative to science for the elementary major and the general education student. Each college and university should seek to establish an integrated, well-balanced program designed to introduce prospective elementary teachers to mathematics, to modern biology, and to physical science through laboratory oriented courses, as well as to the latest methods of teaching science and mathematics in the elementary school. To be successful, these courses must be planned and taught by competent scientists with a continuing commitment to teacher education, working in cooperation with each other, with the school or department of education at their institution, and with practicing elementary school teachers in their community.

These courses should be taught in every case by the consistent use of the most appropriate and imaginative teaching methods known. Finding scientists who are willing to make the necessary commitment is seen as a difficult but urgent problem. A sample program which might be of suitable length and balance is suggested below, but individual schools are encouraged to experiment with programs which differ more or less widely from this. In particular, constant experimentation should be taking place in each institution to find new ways to solve the problems of expanding knowledge, the growing number of students, and increased costs.

The suggested sample program is:

Freshman year - a full year of mathematics
Sophomore year - a full year of physical science with laboratory

Junior Year	-	a full year of biological science with laboratory
Senior Year	-	a full year of the methods of teaching science and mathematics

It should be pointed out that, while these courses would be created with the needs of the elementary school teacher in mind, the first three of these could serve a much wider audience of nonscience majors. It would be desirable to integrate such a science program with courses in other subject matter areas and with professional education courses.

Inservice Education

An important role is being played by inservice institutes in refreshing and extending the science education of elementary school teachers. Each local school district, with the help of colleges and state departments of education, should accept responsibility for providing opportunities through inservice workshops for the continuing education of their teachers and administrators. With no end of the information explosion in sight, there is good reason that the need for inservice institutes will continue to increase in the future.

The Importance of the Child

The teacher must understand children. There is a great need for research in the ways that children think and learn. The lack of understanding of how children think often results in poor teaching. When a teacher tries to teach an idea in a way that the child cannot conceptualize, no learning takes place. The ability to verbalize does not necessarily imply comprehension.

Implications for Curriculum

Science courses for prospective elementary teachers should reflect the needs of elementary school children. Science should be humanized, and interrelationships among the disciplines should be emphasized. Ecology is one of the most important ideas of science to teach to elementary school children. The students should develop an appreciation of and an interest in the world around them.

The best science courses for prospective elementary teachers should reflect the nature of science. Content and process in science are inseparable. This is one reason why the laboratory is such an important part of the science program. Open-ended laboratory exercises are excellent teaching devices and should be used often. Students should have the opportunity to get together to analyze the results of their experiments and to discuss their conclusions.

Summary

Presently, there is very little critical thinking being done by students in college science courses. Often the excuse given for eliminating this process is that it is a relatively inefficient teaching technique, or because it disrupts the class routine. If we develop a mode of thinking in college students--as we recommend that teachers do for children--the students might in turn learn to use the reasoning process which would ultimately lead to creativity.

RECOMMENDATIONS FOR COLLEGE BIOLOGY PROGRAMS

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The same complex of social, political, and scientific pressures and ferments that helped produce the new and better programs of science education on the secondary level ultimately led to the creation of the Commission on Undergraduate Education in the Biological Sciences (CUEBS). Originally spawned by the Education Committee of the American Institute of Biological Sciences, CUEBS is now operating independently under an NSF grant to the George Washington University. The major role of the Commission is to capitalize on the many changes now taking place in patterns of biology teaching--changes that are affecting introductory courses, entire curricula, and graduate programs; that are bringing unfamiliar course titles into the curriculum; that are involving many of our top research scholars in the problems of undergraduate education. None of the changes in education, of course, can rival the dramatic advances in the science of biology itself. It has been the attempt to mirror the new-found scientific knowledge in the undergraduate curriculum that has guided the development of the new programs.

The new curricula have been discussed and criticized in a series of conferences held by CUEBS throughout the country. At these conferences there was almost unanimous agreement that all future biologists, regardless of eventual specialization or employment, need a "core" of common biological training extending well beyond the confines of a typical one-year introductory course. As the core has expanded to two years or more, it has added material primarily from the areas of molecular, cellular, developmental, genetic, and environmental biology. This has resulted in the displacement, but not complete loss, of material from such "traditional" areas as comparative and descriptive morphology, comparative physiology, phylogeny, and natural history. A strong component of organismic biology remains in all programs.

Although there are striking differences in the organization of these core programs, they show a considerable degree of convergence on common subject matter. In most of them biochemistry, cell biology, genetics, developmental biology, and ecology are conspicuous, regardless of the specific course titles.

There is unanimity among the programs and among the conference participants that two years of chemistry, a year of physics, and mathematics through calculus are essential to the preparation of biology majors. Additional courses beyond the core are, of course, required but these can be elected according to the student's interests.

There was general agreement at all conferences that the core should be structured--it should be something more than as ensemble of unrelated courses. Various types of structuring were proposed.

Some favored initiating core studies at the organismic level; others at the cellular level, and a few, at the molecular level. Others proposed theme or problem approaches with such topics as evolution, regulation, the steady state, and others as the thesis for the organization. It was suggested that within each biology faculty, or between faculties of botany and zoology in an institution, there should be cooperative efforts to develop offerings that have a common focus or pattern of complementarity.

Several of us at the conference were impressed with the similarity of this set of recommendations and the one which came from an earlier conference which resulted in the publication, "Recommendations on Undergraduate Curricula in the Biological Sciences."[6] You may be familiar with that report, often referred to as the report of the Chapel Hill conference. We are not dealing with new problems, but old ones. The committee which produced the Chapel Hill report had no way of implementing its work. As I see it, CUEBS does. To this end, CUEBS has established eleven action panels,[7] covering the gamut of undergraduate biology, to consider how best to catalyze the adoption and adaptation of the new programs by a variety of institutions.

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[6] National Academy of Sciences--National Research Council, Washington, D. C. 20418. Publication 578, 1958.

[7] Information available from Commission on Undergraduate Education in the Biological Sciences, 1717 Massachusetts Avenue, N. W., Washington, D. C. 20036.

NEW DIRECTIONS IN COLLEGE CHEMISTRY

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A number of exciting innovations, both in new types of courses and in curricula, are being made in an increasing number of colleges and universities. These changes have been made in view of the shift of interest and emphasis of specific subject matter from one field of chemistry to another and because of the entering students' improved background in science and mathematics resulting from the upgrading of high school programs. Examples of changes that have been made are discussed in detail in the report, "Experimental Curricula in Chemistry," prepared by the Committee on Curriculum and Advanced Courses of the Advisory Council on College Chemistry.[8]

Major attention has been given to the first-year course in chemistry. Instead of presenting in the first year traditional general chemistry, some institutions are offering a course that is primarily organic chemistry, while other institutions are emphasizing elementary physical chemistry. In other cases, the subject matter involves mainly physical principles and bonding theory rather than descriptive inorganic chemistry. The accompanying laboratory work emphasizes quantitative techniques previously presented in conjunction with the traditional quantitative inorganic analysis course. Much of the laboratory work emphasizes major concepts and principles.

There is an increasing tendency to offer physical chemistry as soon as possible in the curriculum. Physical chemistry has become a prerequisite for analytical and inorganic chemistry as well as for all of the advanced courses. In general, a course in organic, physical, analytical, and inorganic constitutes a basic core of courses in the curriculum to be given during the first three years, and followed by a group of advanced courses, including independent study, offered during the senior year. Instrumentation continues to become an integral part of the curriculum at all levels.

The changes in course content have resulted from the shift of subject matter from one field of chemistry to another. Although ionic equilibrium and electrochemistry traditionally were included in physical chemistry, these subjects are now being presented in analytical chemistry. Kinetics is now being developed in organic chemistry rather than being included in physical chemistry. Questions are being raised as to how much physical interpretation should be given in an organic course and how soon the mechanism of organic reactions should be introduced. Because of the deletion of descriptive inorganic chemistry from the first-year course, more attention is being given to this topic in the inorganic course. At the same time, many institutions are re-examining the organization of topics throughout the entire curriculum to avoid needless duplication and to prevent the omission

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[8] Available from Advisory Council on College Chemistry, Department of Chemistry, Stanford University, Stanford, California 94305

of any significant topics. Whenever possible, the subject matter is being considered from a quantitative point of view rather than from a qualitative point of view.

The basic core of courses recommended for a student preparing for industry or graduate school also constitutes the most useful program for those students planning to teach secondary-school chemistry. In order for the chemistry teachers of tomorrow to present modern chemistry to their students, it is essential that they receive the best possible training in the four basic fields of chemistry, including an opportunity to participate in an independent study program to obtain the fundamental aspects of research. Ideally, advanced courses in inorganic, organic, and physical would give these future teachers the necessary depth of understanding of chemistry that is so essential for them to present modern chemistry to their students.

UNDERGRADUATE PREPARATION OF RESEARCH SCIENTISTS

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To begin with, I would like to make several assertions which I believe are pertinent to the discussion. The first is that there is a strong requirement for versatility in the researcher. This is becoming increasingly true because of the greater emphasis on multidisciplinary research programs and because of the rapid evolution of research technology. The second aspect that I wish to emphasize is the increased demand for reporting, arising, partly because of our increased predilection to paper and because knowledge held within the mind of one man is not important for humanity. It is only when research results are reported and utilized that they become important and that they provide evidence that the money for the research was properly spent. The third point is that of intrinsic salesmanship. Although many of us may adopt an apologetic attitude, we still engage in the business of selling programs; or trying to obtain support for research; of trying to convince our colleagues that a particular piece of work is worth doing; of trying to convince our superiors that we are going down the right road; and of trying to convince the company management that research pays, both in the short term and the long term.

To emphasize the requirement for versatility, we have only to look at the important field of civilian electronics. If you examine the management and working structure of Admiral Corporation, for example, you will find that the men at the executive level were indeed trained as engineers but were directed toward the business of large electrical power plants and transmission lines. But then someone invented the vacuum tube, and these men all had to learn a new kind of business. Perhaps the younger executives were more fortunate in that they arrived on the scene with training in electronic circuits using vacuum tubes and were able to go directly into the business of developing better AM and FM radios, better Hi Fi sets, and better black and white and color TV's. Like their superiors, many of them had to undergo rapid change and reorientation when the solid state era of electronics began. The young engineer coming in today has all the advantages of training in the modern areas but will no doubt undergo considerable change in the coming age of microelectronics. It is interesting to note that the fundamentals are often neglected in the effort to train engineers who are ready to go to work productively after their graduation.

I remember, for example, asking several young electrical engineers the question "Which has the greater induction per unit length, a small wire or a big wire?" All of the old-timers knew the answer to the question but a majority of the most recent graduates missed it. I believe that if you made a survey of the field today, you would find a very small percentage of electrical engineers capable of beginning work productively without considerable on-the-job training to augment their academic training. Likewise, you will find that the majority of them in business over ten years have had to invade new fields and learn from scratch. In other words, we live in a dynamic and changing world, especially in the area of science and engineering.

As I mentioned earlier, there are increasing demands for the reporting of the results of research. Part of the demand is a result of greater emphasis on specialization; part of it is because many of the findings are too complex to be deposited safely in the inner recesses of the human memory; part of it is due to increased visibility demanded by today's executive with electronic aids at their disposal; part of it is due to the "publish or die" attitude of our educational institutions; part of it is the result of the ease with which reports can be prepared and reproduced with present-day technology.

One of the most effective administrators I have ever known placed an almost irrational emphasis on clear reporting. He claimed that he had never seen a really top-notch engineer or research man who could not express himself well in writing. I will have to say that I believe Socrates when he expressed the opinion that any man who has a worthy thought will always find the words in which to express it. I believe also that most of us have the human weakness of desiring to talk about ourselves and what we are doing. I believe that the man who is really productive and who is aware of the rewards of productivity will naturally wish to tell others about what he has done. I believe that the man who has his company's interest at heart will naturally wish to protect his employer by adequate documentation in the form of patents, reports, and journal publications. I must admit that I personally do not think a scientist or engineer has had a proper education if he cannot perform a piece of research and write a lucid and well-organized report on the findings. I am assuming here that the researcher likes his research, is proud of it, and is sure of its validity, and the reporting of it is in a different category than the impersonal and often objectionable theme assignment in composition class.

The hermit of ancient times is about the only human I have heard of who has avoided the necessity of salesmanship. When we go in to ask for a raise and advance the arguments for why we deserve it, when we tell how excellent our company is when we are trying to get a contract, when we try to motivate the management to start research in solid-state physics, or when we write to our Congressman to ask for more emphasis on defense spending, we are resorting to one form of salesmanship or another. This involves the capability of expression and the knowledge of the philosophy and feelings of the man to whom the sales pitch is directed. This salesmanship may involve much more than the operation of an infrared spectrometer or the measure of characteristics of a transistor; it involves human relationships.

To summarize my position, then, I believe that the engineers and scientists of today should have a broad base in the liberal arts and the humanities. We cannot argue extreme specialization in education if we believe that a man goes out into a changing world, perhaps to a position which evolves into something totally different from that for which he was initially employed. We can argue, however, that a man's chance of adapting to new developments is better if his background is broad and if he has been exposed to a variety of multidisciplinary approaches. I might say in closing that the records of enrollment at many colleges and universities have shown that the students arrived at these truths before the professors admitted that the

curriculum needed changing. I believe that one can point to several colleges with extremely strong engineering orientations which suddenly awoke to the realization that their students were enrolling heavily in the basic science courses. One last point--I believe that education of our young people should be accelerated as rapidly as possible so that the man or woman is not middle aged before he or she is plunged into the exciting business of research. In our NASA graduate assistantships, we have worked hard to realize this state of affairs. I sometimes wonder if the regimentation and restriction imposed by education over a long period of time is not one of the most effective ways of removing enthusiasm and originality from our young people. My opinions here are that order and organization are desirable when they serve a purpose in a way that is clearly demonstrable and do not stifle individual achievement. It is hard to argue for flexibility in a world of transition if we cannot accept the reliability of individuals operating independently and responsibly without the full direction and supervision of the machine which we call our educational or research institution. It is my hope that the academic world can so infuse the student with the value of independence and self-discipline (in others as well as himself) that he does not lose his perspective when he becomes a part of the extremely organized machinery of industry and government and moves up the management ladder with the aid of the versatility that you have given him.

SUMMARY OF DISCUSSION GROUPS

The Preparation of Science Majors

While suggestions for specific subject areas are somewhat diversified, there are a few problems that are common to most, if not all, subject areas. Three of these problem areas are important enough to merit special attention before dealing with the specific subject areas.

Introductory Science Courses

Because of the increasing emphasis on the interdisciplinary aspects of science, there is a need for basic introductory courses in all subject areas before specialization in the major field. The extent to which this is necessary varies somewhat for different majors; the more noticeable change has occurred with the biological sciences. Contrast today's situation with that of a generation ago, when a year of chemistry might have been the only related science considered necessary for biology majors, and no one considered mathematics. The one group that considered this specific problem recommended that inorganic and organic chemistry, at least a year of physics, and a year of mathematics should be required for all students. This group also recommended that calculus should be encouraged, especially for such special programs as that for premedical students. A chemistry group expressed the opinion that every biology, chemistry, and physics major should have a basic knowledge of each of these three areas and of mathematics through introductory calculus.

Considerable attention was given to the need for giving special considerations to the wide divergence of backgrounds possessed by various entering freshmen. Recommendations varied from the possibility of eliminating the introductory course entirely through advanced placement for capable students to providing an introductory course that might remedy common deficiencies of high school students, including introduction of new course materials at the commencing level and the introduction of research-oriented problems into laboratory work.

Emphasis on Principles

There was strong indication of a move away from emphasis on factual information and a trend toward emphasis on principles and key ideas in each subject. This is often done within the framework of existing courses. Course content and emphasis have been changing much more rapidly and significantly than course titles. This could pose a problem for those institutions that have not kept in touch with current changes, lulling them into a false sense of security because they do not recognize the changes that are taking place within some institutions. It is becoming increasingly apparent that course titles, and even catalog descriptions of courses, do not provide a valid basis for assessing the nature of the courses described. For example, "Chemistry I" might represent anything from a descriptive course *circa* 1930 to an introductory physical chemistry course of the most rigorous variety.

The Role of the Laboratory

There is general indication of dissatisfaction with existing laboratory procedures and practices. There is general agreement that laboratory work should be imaginative, research-oriented, and challenging to the student. Participants seem to be equally agreed that present practices often fall short of these goals. In no other area of science teaching is the gap between theory and practice as wide or as visible.

Laboratory instructors are faced with two major problems: the influx of students in large numbers, and the apathetic reaction of many students to present varieties of laboratory work, especially at the introductory level. Among the approaches suggested to maintain vitality and usefulness of the laboratory were (a) the concept of a "library" of laboratory experiments, (b) the use of programed instructional material as a mechanism for guiding laboratory work where large numbers of students are involved, (c) a systems approach in which a set of laboratory experiments build sequentially to the examination of some fairly complex phenomenon, and (d) the development of research-oriented experiments that are clearly correlated with the lecture material.

No one was willing to claim that a good science program can be taught without laboratory work. On the contrary, there was general agreement that the laboratory had a vital place in the science program, although it needs considerable improvement. There is considerable evidence that many schools are taking "stop gap" measures for alleviating immediate problems, instead of tackling the real problem of complete revision of laboratory design and practice.

Flexibility in the Curriculum

Discussion group reports reflected a growing concern that there is a danger of overstandardizing the curriculum, discouraging experimentation and innovation. Several of the groups emphasized that general suggestions should not be considered as standards, and that there is a need for each institution to develop a unique program designed to meet the objectives of the department and the institution.

Also, there is an evident need for flexibility within the curriculum of an institution, to provide for individual differences in student backgrounds, student abilities, and varying student needs due to differences in future goals.

Biology

In addition to the suggestions for increased emphasis on mathematics and the related sciences, one strong recommendation appeared. For biology majors, there was a wide acceptance of the idea of a core curriculum in biology, requiring at least two years, which would include molecular biology, cellular physiology, modern genetics, developmental biology, organismic biology, population and community relationships, and evolution. Also, a strong plea was made for continual attention to the need for continued curriculum revision.

It will not be easy to find biology teachers who are competent to teach such integrated courses. Rather than using this as an excuse to continue with traditional programs, there needs to be adequate continuing education for college teachers whenever necessary. Also, a reduction in teaching load is essential for the success of such a program.

Physics

There is a need, both at the introductory level and beyond, for new course materials which more clearly reflect the present nature and structure of physics. Especially for students who plan to be high school teachers, physicians, lawyers, or businessmen, new course materials are needed. These should have a more phenomenological approach and should strive for depth of understanding of some basic ideas rather than for all-inclusive, but superficial, coverage. In them the elements of synthesis and of physical insight and intuition should be present in large measure to complement mathematical analysis.

Innovations in course materials may help to reduce the apparent prejudice against physics shown by individuals who consider it an austere and grimly analytical subject. College physics instructors should devote more attention to encouraging more students, particularly women, to enter the field of high school physics teaching. Also, prospective elementary teachers should be given more encouragement to take an introductory college physics course. The obvious corollary of these suggestions is that physics instructors have the responsibility of designing physics courses that would be helpful and challenging yet within the comprehension of such individuals.

In general, the emphasis of college physics courses should be on depth with the development of fewer major concepts. Such courses should include a number of individual assignments which require more student planning and problem solving. Several pertinent questions, asked by one discussion group, are worth considering:

1. What techniques may be used to get better understanding and support of science programs by administrators and other educators?

2. What may be done to improve the contribution of physics courses for students who are majoring in other fields?

3. How may physics courses be accelerated and still provide time for the student to digest the work properly?

4. In many colleges the enrollment in physics classes is decreasing. What are the possible causes of this trend, and what methods may be used to increase enrollments?

5. How may we reduce the gaps that exist between high school and college physics courses and between the college and the graduate school?

Chemistry

Organization of chemistry courses is dependent upon the local

situation. A course of study will depend upon the quality and capabilities of the student body and faculty. Stimulation and motivation by the professor is important. Course content should emphasize firm establishment of basic concepts utilizing essential facts.

The chemistry major should have basic courses in inorganic, organic, physical, and analytical chemistry. Mathematics should be required at least through differential equations, and physics through atomic and nuclear physics.

Lecture experiments, if really carried on as experiments for the collection of data, might enable the novice to participate in the research type of experience so as to gain more of the feeling of the meaning of the methods of science. Yet, certain laboratory work on an individual basis is essential. Experimentation should be of such a nature that students take sufficient time for a laboratory experience to ensure an understanding of the problem to be solved, to develop a method to be used, to realize the proper method of collecting and evaluating data, and finally, to draw conclusions.

The Earth and Space Sciences

The earth and space sciences are not new fields in science, although they deal with many topics that have only recently received attention at the public school and undergraduate college levels. These topics are drawn from astronomy, geology, meteorology, and oceanography, and in many instances introduce interrelated aspects of the subjects. Recent impetus given to research in the earth and space sciences has resulted in the rapid expansion of new knowledge in many other disciplines, including astrophysics, geophysics, geochemistry, and space biology.

Much of this knowledge is new to many science teachers, and consequently is neglected in teacher preparation and in suggesting scientific careers for students. However, we must realize that children who are now in the first grade have <u>always</u> lived in the space age and calmly accept the great discoveries and new advances in space science that astound adults. These children are living in a universe with greatly expanded frontiers. We will do them a great disservice if we do not provide them with some understanding of knowledge in this area.

The earth and space sciences today, more than ever before, rely on basic principles of biology, physics, and chemistry, and require considerable knowledge in mathematics in working with them. Increased emphasis on the earth and space sciences can provide a powerful motivating factor for students to learn more basic science and mathematics.

It is apparent that earth and space science are being taught at three levels: to elementary and secondary students in kindergarten through twelfth grade, at the undergraduate college level for general education students as well as to prepare both elementary and secondary teachers, and at the graduate level to prepare research scientists, engineers, and technicians. Colleges and universities need to provide adequate instruction at the undergraduate level to prepare elementary and secondary teachers in these areas of science. Also, there is need for inservice courses to provide elementary and

secondary teachers with adequate backgrounds for teaching the earth and space science as new curriculum programs are adopted.

Inclusion of the following elements would help to strengthen the undergraduate preparation in this area:

1. A good preparation in basic science and in mathematics through introductory calculus

2. Imaginative, laboratory-centered introductory courses in astronomy, geology, meteorology, and oceanography (It might be difficult for some colleges to include laboratory work in oceanography, but there are many laboratory activities that could be suggested in the other areas.)

3. Enough work in some area of the earth and space sciences to enable the graduate to pursue a master's degree in some aspect of this area

4. Greater emphasis on instruction in the earth and space sciences for elementary and secondary teachers

5. Provision for inservice education and summer institutes in the earth and space sciences

Conclusions

Problems of science education are not confined to general education courses for nonscience majors. There is a pressing need to reevaluate the entire undergraduate science curriculum and to introduce new and more refreshing techniques of teaching. We need to eliminate much outdated and trivial subject matter, to avoid needless repetition, to agree on uniform ways of presenting science topics in various fields, and to revise the content of courses to include new knowledge and principles. In general, this may be accomplished by redesigning the undergraduate science curriculum to utilize better instructional techniques as well as to provide better continuity and, by preparing students to teach, to carry on graduate work, and to understand the world of science and technology in which they are living.

TRENDS AND IMPLICATIONS FOR ACTION
IN COLLEGE SCIENCE PROGRAMS

Several groups of college teachers were asked to consider general problems of science teaching, without reference to subject matter or specific topics. These groups made several significant observations that might be of value to curriculum committees who are reviewing the practices in their own institutions. These suggestions have been incorporated into this section, together with pertinent ideas that have appeared elsewhere in the conferences.

The Need for Change

Introductory science courses are changing, and to maintain vitality in the science curriculum, continuing changes must be made in all courses. There are too many experimental courses still in the process of development to enable an observer to say what changes now being explored will--or should--survive. The successful changes in college programs will involve recognition of the new high school programs in science and mathematics, as well as those that will be developed in the future. Much of the technology once included in basic high school physics and chemistry courses is now being taught in the junior high school, and even in the elementary school. Introductory college courses must change to adjust, even more than they have at present, to the effects of these courses, including the increased emphasis on basic principles rather than on facts.

The Student and the Course

An important problem is the motivation of the student. We should emphasize in our thinking and teaching that a subject is required because students need or will need it, and not because the course is required for graduation. It is more effective to organize sections in science courses according to ability to achieve--mathematics and English achievement have been found to be good criteria--than by professional goals such as scheduling physics for agriculture majors or for music majors. In any case, to be effective, the teaching must be suited to the student, whether the organization is in a single compromise section or through individual guidance involving laboratory-centered projects for each student. Instructors must experiment with teaching methods, even if their colleagues frown upon such experiments.

Great strides have been made in secondary education, but the college and university have lagged behind the secondary school in terms of a realistic appraisal of what is important to learn in science and how students learn. Courses such as that of the Physical Sciences Study Committee (PSSC) have taken a few million dollars and the time and cooperation of many professionally prepared people, including hundreds of classroom teachers, to reach their present development. If the same amount of time, money, and cooperation were available, a college course in science based on underlying concepts could be developed. This course might be effective in giving to all citizens a more realistic picture of science. Perhaps we have reached the point where a project of this sort should be attempted. However, the difficulty of deliberating on the nature of science education

for nonscientists is made no easier by the fact we are uncertain regarding the essential elements of science education for scientists.

Designing Courses

Much of the present college science curriculum is unsuitable for students' present and future needs. Course content and teaching techniques should be continually evaluated and revised. This task is the responsibility of the entire science staff and should not be delegated to a few individuals.

We need to introduce new and innovative practices, particulatly in the laboratory. We need flexible course plans taught by instructors who are willing to try new ideas. Each course should offer students the greatest challenge possible so that they will become aware of the importance of the course and its relationship to the rest of the curriculum. Some of the unrest in the schools and colleges of this country may be attributed to dissatisfaction with the traditional curriculum, due to its failure to meet the needs of students and to challenge their thinking.

In plans for course content and suggestions for teaching techniques, it is important to remember that education is a lifelong task. It is not completed when the last examination is concluded and final grades are received. Both the instructor and the institution have failed to achieve a primary objective of higher education if the student is not inspired, as a result of having taken the course, with a continuing interest and desire to study further in the area.

Subject-matter walls are a hindrance to understanding science and should be broken down. This may necessitate interdisciplinary seminars for those professors who do not feel adequately informed in other disciplines.

The preparation of scientists requires continuing specialization, although it should be noted that many of the significant discoveries are now being made by those with interdisciplinary backgrounds, or working in interdisciplinary areas. On the other hand, undergraduate science instruction requires greater breadth of knowledge, particularly for teaching introductory courses. Perhaps we have reached the point in higher education when we should encourage careers in the teaching field and give professors equal recognition, including opportunity for promotion for successful work in this field, as well as for research.

Unless four-year colleges give more attention to revising and improving introductory courses, there is the possibility that we will turn to the European practice of beginning university work with the third year of college. This trend is already apparent. In many places, the junior college has met this need, and soon more than 50 percent of our students will take their first two years of college work in junior colleges. Perhaps this trend should be accelerated.

CONCLUSIONS

In reviewing the reports of these college conferences on science, one gets the impression that some college professors "are in favor or progress but are opposed to change," as one conference participant put it. This may be due, in part, to their failure to realize that they have a responsibility to keep their teaching techniques and the content of their courses, as well as their knowledge of science up-to-date. There is a vital need for better communication among college teachers, as well as a need for greater interest in the beginning science student. There is a great danger that the creative student may become disgusted with introductory science courses and turn from science to courses where he will find imaginative approaches. There is also a great danger that the nonscience major may develop a prejudice against science that will continue throughout his adult life. Imaginative solutions to these problems will never be reached until college professors recognize that nothing less than excellent science teaching can be accepted in every class and for every student.

This problem does not have a simple solution. Science departments are faced with interdisciplinary rivalries, conservative attitudes, and a fear of the increased knowledge resulting from the "information explosion." Many faculty members are confronted with the danger of "loss of face" due to a changing emphasis on the relative importance of specific subject matter in science. Solutions will not be easy to find. Professors must face the fact that a considerable proportion of their time is required to keep up-to-date with changes in science, even at introductory levels. They must constantly revise the courses they teach. And they can never feel secure to relax and be content with their present knowledge.

Another problem faces many college professors. Extreme specialization, which has been the goal of the research scientist and many professors, will no longer provide an adequate preparation for teaching introductory courses and for conducting many types of research. Any college teacher should be ashamed to admit that he lacks an adequate breadth of knowledge in science to teach an introductory course or a general education science course which cuts across subject-matter lines. Yet, this is the excuse used far too commonly by college teachers when they are asked to teach such courses. Perhaps scientists should re-examine their practice of extreme specialization when it is carried to the point where they lose contact with the outside world, or even with new developments in subject fields related to their field of specialization. It has been a hard fact of life, as first stated by Darwin more than a century ago, that the ability to adapt to changing situations is more important to survival than extreme specialization.

Present developments in college science teaching are encouraging. One hears of new courses being developed and new techniques being tried in science courses all over the country. College teachers were instrumental in accelerating the movement for revising the elementary and secondary school science curriculum. They are now beginning to turn their attention to their own courses. It is possible,

even probable, that the present movement for reforming the curriculum will result in profound changes in curriculum and teaching techniques at all levels within the next one or two decades. There is no doubt that the college and university faculties will play a vital role in implementing this change.

This publication, and the conferences from which it has been developed, were planned to alert college science professors to the immediacy and critical nature of the problems with which we are faced. There is considerable evidence that the higher education establishment, once it really becomes aware of these problems, is capable of finding solutions and redesigning the curriculum to meet the needs of a changing society.