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This is a working paper prepared as a report on the general problems of course improvement and curriculum reform in science teaching. Discussed are education and the spirit of science, the impact of science and technology on economic and social education, and criteria for a program of action, course improvement and curriculum reform in science, and specific recommendations for concerted action in science teaching improvement in developing countries. The appendices consist of a review of modern methods, techniques and materials in science teaching improvement; national, regional and international course improvement and curriculum reform activities in science; and the concern of the United Nations specialized agencies and of other international organizations for the improvement of science education. (BR)

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SCIENCE EDUCATION

Improving the Teaching of Science with Particular Reference to Developing Countries

Working paper prepared at the request of the Secretariat of the Advisory Committee by its consultant, Dr. Albert V. Baez, member of Harvard Project Physics of Harvard University and former Director of the Division of Science Teaching of UNESCO.

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IMPROVING
THE TEACHING OF SCIENCE WITH PARTICULAR
REFERENCE TO DEVELOPING COUNTRIES

A report on the general problems of course improvement and curriculum reform in science teaching with an appendix on modern methods, materials and techniques.

I. EDUCATION AND THE SPIRIT OF SCIENCE

Summary: The spirit of science is the particular approach to rational inquiry exemplified by scientists, driven by a belief in its efficacy and by a restless curiosity. In organizing a concerted attack on science education it is not sufficient to plan only for the training of more and better scientists and engineers. It is necessary for educators to devise broad curricula in which the spirit of science is accorded a more explicit place among the many goals of education.

1. There is an international concern for science education which began with national movements for reform about fifteen years ago, and there is now also an international awareness of the need for a concerted attack on this important problem. After World War II scientists in several countries discovered that the science textbooks used in schools were badly out of date. Some of them broke with the traditional lack of concern of scholars toward pre-collegiate education and became leaders in the modern reform of science and mathematics teaching. The initial successes in the advanced countries stimulated similar activities in the less developed nations.

2. Under the guidance of these scientists at least two of the basic questions in science education were dealt with imaginatively and productively: what to teach and how to teach. This section addresses itself, on the other hand, to a third question - why teach science? Before dealing with content and methodology, therefore, we shall discuss purpose. Our thesis is that in planning a concerted attack on science education it is not

sufficient to plan only for the preparation of more and better scientists and engineers but that it is necessary for educators to devise broad curricula in which the spirit of science (1) is accorded a more explicit place among the many goals of education.

3. In the modern world the approach of rational inquiry - the mode of thought which underlies science and technology - is spreading rapidly and, in the process, is changing the world in profound ways. Science and technology have presented the world with a constant progression of phenomenal successes; and, understandably, the type of attitude and activity which accounts for those successes is regarded with increasing prestige. The particular approach to rational inquiry, exemplified by scientists, driven by a belief in its efficacy and by a restless curiosity, we shall call the spirit of science. It can and should also infuse many forms of scholarship - religious, aesthetic, humanistic, literary - besides science itself.

4. Curricula in schools and universities, particularly those in science, should be continuously revised to promote the spirit of science whose characteristics and values include the following:

1) Longing to know and to understand
2) Questioning of all things
3) Searching for data and for relations among them that may give them meaning
4) Demand for objective verification

5) Respect for logic

6) Consideration of premises

7) Consideration of consequences

5. The above are guidelines for belief and hence for action. Some of them merely exemplify traditional values; the longing to know and the demand for verification, for example, can imply honesty, reliability, and responsibility; every practitioner of science depends on the honesty of other scientists. Each realizes that this requirement also rests on him. The pursuit of truth is impeded by a lack of mutual trust and faith. Love of one's children and a responsibility to one's neighbors, on the other hand, exemplify an awareness of consequences. Although these guidelines are those of science, therefore, and although science is often said to be neutral on questions of value, there are many ethical implications which flow from these scientific beliefs. Like other guidelines, they have the defect of not providing a complete pattern for action. In many concrete human situations, various values are involved and a choice of action involves an ethical compromise. The spirit of science expresses the belief that the compromise is likely to be better if based on thoughtful choice; in this respect it differs from other guides which hesitate to submit all problems to reason. It differs, for example, in the degree of reliance it places on the individual. Instead of insisting on his acceptance of certain values favored by men or groups allegedly wiser than he, the

spirit of science insists that he make up his own mind, expressing thereby a humane value - the belief in human dignity. What is advocated here is development of individuals whose approach to life as a whole is that of a person who thinks and acts in accordance with the spirit of science.

6. Here, then, is a set of guidelines which schools can utilize without doing violence to the dignity of the individual. They represent values which are not intended to be accepted on the basis of external authority. The schools here envisioned would have failed in the case of any student who has never compared the various bases which different men deem sufficient for knowing or for acting. The view of teaching as the indoctrination of superior knowledge and wisdom here gives way to a concept of teaching as promotion of the development of the learner from within. In this way, schools can be profoundly concerned with values and ethics in a manner fully consistent with the scientific belief that no one - the school included - knows the final answers.

7. The spirit of science applies to other facets of man's existence. It fuses with many kinds of thinking that men traditionally consider distinct from it. The view that there is a necessary conflict between the scientific and the humanistic approaches to life is not valid. When science is isolated from the moral and spiritual aspects of life it can produce the monstrosities so often feared, just as the acceptance of

values on the basis of emotion and without rigorous examination of their likely consequences has often produced abominations.

8. The spirit of science should permeate the educative process, serving as a guide for learning in every field, including the humanities and practical studies. All parts of the educational program should reflect the unity of life. All subjects can be taught so that they contribute to the student's tendency to examine all concepts and to inquire into the social implications of the questioning spirit. The thorough compartmentalization of subjects in a school is in conflict with the best interests of human development. The schools must try to give unity to the curriculum. They must continue to sensitize students to the aesthetic and ethical aspects of civilization.

9. It cannot be assumed, however, that the mere addition of science courses to a curriculum would necessarily contribute to the achievement of these goals. One of the reasons science teaching needs improvement is, in fact, that science is sometimes so taught as to be irrelevant or even opposed to their achievement. Efforts to discourage challenges to traditional beliefs and attempts to indoctrinate are probably widespread at present in every school system, however advanced the content of its science courses. What is needed is an education which turns the pupil's curiosity into a lifelong drive.

10. Implicit also in these guidelines is a modesty or humility which contrasts with the boastful self-assurance of arbitrary authority. A man of science is suspicious of any claim of certainty. He insists that no concept, proposition, or belief is immune to examination and possible rejection. He is willing to see even his own conclusions challenged. He recognizes his own failings and those of others. He knows that no observer, thinker, communicator, corroborator, or other human link in the scientific process is perfect.

11. It cannot be guaranteed that a society which seeks the scientific spirit will avoid repetition of the cruel acts with which history is replete. Wars have repeatedly been fought by men who professed belief in religious faiths devoted to peace. Science might be similarly distorted by scientists. But such distortions are neither required nor justified by scientific traditions. If they arise, it is not from devotion to the spirit of science, but from the failure of men to be guided by it.

12. The spread of science and technology may carry seeds of a most hopeful future for man. At present the most visible aspects of international relations are nationalism, hatred and violence. They make the headlines, and their genuine significance cannot be denied. But there may be a deeper tide in world affairs, a tide too quiet to produce headlines but of overwhelming

importance to the future of mankind. That tide is the development of a common commitment to the spirit of science which, by guiding the thoughts and actions of only a few persons in a few countries over a comparatively short time, has already given man unprecedented powers to perceive, to understand, to predict, to control, and to act.

13. The profound changes men have wrought in the world by their uses of science and technology have been for better and for worse. But the spirit underlying science is a highly desirable spirit. It promotes individuality. It can strengthen man's efforts in behalf of world community, peace, and brotherhood. It develops a sense of power tempered by an awareness of the minute and tenuous nature of one's contributions. Insofar as an individual learns to live by it, he achieves an invigorating sense of participation in the spirit of the modern world. To communicate the spirit of science and to develop the capacity of individuals to use its values should, therefore, be among the principal goals of education.

II. THE IMPACT OF SCIENCE AND TECHNOLOGY ON ECONOMIC AND SOCIAL DEVELOPMENT

Summary: Science and technology are valued because they have brought economic and social benefits including a higher standard of living and better health to many people. They also promise two less tangible but equally profound benefits: increased individuality and the possibility of increased brotherhood among men. They have, on the other hand, also produced a host of painful problems. They have disrupted traditions, increased the gap between the rich and the poor and produced weapons of mass annihilation. In spite of apprehensions aroused by these we conclude that the hopes outweigh the drawbacks and justify a general fostering of the spirit of science through education.

14. In today's world, science and technology interact intimately with each other. Science engenders technological progress; technology in turn makes possible many of the major advances of science. Because of this interrelationship, science and technology commonly receive joint recognition as basic molders of the spirit of modern life; because they both partake of the same spirit of rigorous subjection to test and systematic pursuit of progress; and because they both derive from and depend on the tradition of rational inquiry.

15. The worldwide pursuit and spread of the products of science and technology are commonly recognized. There is less recognition that the values and modes of thought which underlie science and technology also are becoming widely diffused in the world. Yet these values and associated modes of thought may in the long run be more important to mankind than the visible fruits of scientific and technological pursuits. It is for this reason that educational curricula must be devised to teach not only the facts but also the spirit of science.

16. The most commonly recognized manifestations of the scientific

and technological revolution are the material ones. Science and technology are increasingly valued wherever people value their nation's independence, prosperity, power and prestige. They are increasingly valued wherever nations seek a higher standard of living, improved health, or better education. But more is changed than the material conditions of life. Old routines and time-honored patterns of life have been destroyed or profoundly changed. Economic and social systems are modified at an accelerating rate. The methods and results of science introduce a widespread skepticism and willingness to forgo traditional ways in art, philosophy, religion, and social customs.

17. In addition, the scientific and technological revolution affects the very texture of thinking of the common man, the way theology did in the Middle Ages. New or modified values and attitudes, combining to produce a new perspective on life, are gaining importance in the industrialized countries. The spread of technology is accompanied by an increasing respect among all men for utility, efficiency and practical results, and, above all, there is an increasing interdependence among individuals.

18. The most obvious result of the spread of science and technology to the developing countries has been the proliferation of similar institutions all over the world - more industry, more hospitals,

more cities, more schools, more reading materials, more people, more aged people, more electric power, more vocational and professional organizations, more scientific farming, more movement from farms to cities, more communication and transportation facilities, more (though not always more real) popular participation in government, more governmental particiaption in the economy.

19. Some of the changes accompanying the revolution in science and technology are happy ones -- in particular, the higher aspirations and the possibility of a materially better life for the masses of mankind. But among the results are also a host of painful problems. Some are in the international arena; others are domestic. These changes appear to be inherent in industrialization but in fact they are not. Although they affect every industrializing society, regardless of its cultural background or its professed ideology, they are really due to a sudden and drastic change in social structures.

20. On the international scene the greatest concern is caused by the existence and spread of weapons of mass annihilation. Also of grave concern is the rapidly increasing gulf between the rich peoples and the poor peoples. The present population explosion more than cancels all efforts to narrow the gulf. Other results of a partial use ofescience and technology are: (i) the juxtaposition of primitive and modern agricultural

methods which generates social problems and (ii) the stresses which are produced when people see and hear of better forms of life but are not given the means to attain them.

21. The disruption of tradition is a process which is painful anywhere, but especially so in the nonindustrialized world because science and technology are generally regarded there as a means of making a sudden leap into the future, without, unfortunately, a preparation for the stresses produced by sudden and deep changes in the social structure. Among the traditions disrupted everywhere are old certitudes, particularly religious beliefs. Dogmatic secular beliefs, such as those dealing with politics or race, are also undermined by the persistent demands of technological efficiency and the spread of scientific thought.

22. The impact of science and technology challenges traditions of family relationship as well. Among the many results are a growing use of birth control, a rise in the status of women, an alteration in the concept of divorce, and a decline in the belief that prolific childbearing when young is the best guarantee of security in old age. In an industrial society, it usually takes longer for young people to enter upon an economically productive role, and the years of dependence thus added to each person's life generate problems in the status and behavior of youth. On the other hand, young people now break family bonds more easily

and family life is altered, particularly in the developing nations.

23. As a result of the demands of specialization in a scientific and technological society, the thoughtful, sensitive individual finds it difficult to see life as a whole and is often at a loss for meaning. Changes take place so rapidly that many individuals do not feel secure in the world. In destroying certainties and challenging tradition, science and technology destroy the psychological moorings of many people. Thus, on the one hand, science and technology arouse the expectation of a better way of life, give promise of material satisfactions, and hold forth great possibilities for the development of human potentialities. They give ride to a genuine optimism and excitement. But, on the other hand, they also give rise to anxiety - to a gnawing apprehension of man's alleged loss of personal freedom, of certitude, of psychological security, of identity.

24. The threat that science and technology could lead to a cataclysmic war, provokes - and justly so - great apprehensions about the spread of science and technology. As knowledge expands, awareness grows of the frightful uses to which it can be put, with man ever more efficient at carrying out the deeds of destruction which he has been perpetrating throughout history. But not even this - the most frightening of arguments against science and technology - seems capable of arresting the trend. On the contrary,

there seems to be a hope that reason, which underlies science, will also help men to deal with the great social problems, especially those of war and violence.

25. Leaders and peoples everywhere have been attracted to science and technology for the resulting benefits in power, prestige, standard of living, education and health. Science and technology can provide those benefits; but the spirit underlying science and technology provides two less tangible but equally profound benefits: increased individuality and the possibility of increased brotherhood among men.

26. The promise of increased individuality derives from the very essence of the spirit of science which can enable each person to free himself from blind obedience to the dictates of his emotions, of propaganda, of group pressures, of the authority of others. It can enable him to be aware of the influences which play on him and, to some degree, to determine and to become his own ideal self. There is little basis for the frequently heard assertion that science engenders conformity. If the world's cultures today ensure differences between groups, they have also produced within each group a high degree of conformity among individuals. There is good reason to hope that the scientific spirit may be, not the producer of conformist cultures, but rather the force making possible individual freedom on a

previously unknown scale.

27. Spiritual unity among nations and men has long been a prime goal among thinkers and dreamers. In the past, this goal has usually been sought through some community of values peculiar to a small group, but hopefully to be universalized. Characteristically, each community of values was founded upon a belief in a religious revelation or philosophical orientation which was also peculiar to a minority of mankind. The pursuit of unity along these lines has been perpetually frustrated by its own built-in limitations due to the absence of a universally accepted system of values which transcended religious, philosophical, and cultural grounds. Today, however, the values on which science and technology are based are gaining acceptance in the most diverse cultures. In this regard, the spread of the spirit of science can be an extraordinarily hopeful development. It might produce a new kind of community among the world's peoples - a deeper feeling of mankind's oneness than that to which the few values hitherto shared could give rise. Already, among men who respect the values of science there is the possibility of immediate fraternity and understanding.

28. Many approaches to peace or the prevention of war are tried today. They include international organizations, power politics, foreign aid, and the preaching of brotherhood. All are valuable,

but perhaps it would be at least as hopeful to look for the promise of peace and brotherhood within the first major system of values - that of science - which has shown that it can penetrate any culture.

29. Therefore, aware of the apprehensions aroused by the penetration of the scientific spirit, we conclude that the hopes it offers so greatly outweigh the drawbacks as to justify a major recommendation: that a general worldwide fostering of the spirit of science is wise. The purpose of the rest of this paper is to develop criteria and guidelines for a concerted worldwide program to improve the teaching of science not only in order to provide better scientists and engineers, but also in order to create among men a universal understanding of the spirit of science and the ability to benefit from its fruits.

III. THE NEED FOR IMPROVEMENT IN SCIENCE EDUCATION AND CRITERIA FOR A PROGRAM OF ACTION

Summary: An imaginary look at the ideal school of the future dramatizes the great quantitative and qualitative needs in science education today and suggests operational goals for concerted action. The task is so great that it is doomed to failure unless it is realistically limited in time, scope and objectives. It should stress quality rather than quantity, be limited to the basic sciences and involve scholars in science and education, working in collaboration with teachers and other specialists, to produce new approaches, methods and materials for teaching and learning science and to integrate them into the overall curriculum.

30. At present science education is everywhere in need of improvement. If we judge it by purely quantitative standards, there are not enough schools, qualified teachers, laboratories or textbooks in the world. If we judge it in terms of the quality of its existing components it is found to be even more seriously wanting - the quality of every factor, human and material, is in need of upgrading. If we press for the ideal and ask how many school systems are teaching science so that the spirit of science and a sense of social responsibility are learned along with the facts of science we find that very few, if any, have begun. The reason is clear; the kind of teaching that demands a sense of awareness of self and environment and the consequences of one's decisions is rare indeed. This kind of teaching, which prizes unconventionality, openness, spontaneity, curiosity, and novelty is still only a high ideal to be striven for. There are too many systems of education which seek not free thought but indoctrination, not the release of the learner but his imprisonment in the school. We commonly find an authoritarian relationship between teacher who is master and learner who is subordinate.

31. In order to specify in operational terms what improvement

means, let us imagine that we can look into a classroom of the future several years after a successful, concerted, world-wide attack on science education has been launched; and compare it to what exists today. Here is what we should see as we enter a science classroom of the future:

(a) A well trained teacher, in good health, not too overloaded with work, alert to the individual needs of students, not authoritarian, permitting class discussion, sensitive to and proud of his main task which is not simply to dispense the facts of science but to create a situation in which learning can take place.

(b) A large classroom with plenty of air and light and adequate control over temperature, humidity and noise level.

(c) Students in good health, alert, interested and adequately dressed for local weather conditions.

(d) Mobility and flexibility of desks, chairs, walls, carrels and utilities, with plenty of space for sitting, walking and working.

(e) Not too many students per teacher.

(f) A good blackboard and good chalk or their modern optical and electronic counterparts.

(g) Each student has his own copy of a good textbook (or its self-instructional and self-testing counterpart), modern in content and illustrated to take into account special cultural and regional needs.

(h) Laboratory equipment in sufficient quantity and inexpensive enough so that breakages can be overlooked and so that each student may handle it himself. Students are encouraged to learn not only through their eyes and ears but also through the use of their hands.

(i) Enough pieces of the more expensive types of equipment such as barometers, electric meters, microscopes, etc. necessary for instruction.

(j) The teacher is using a good teacher's manual, written with the help of scientists with lots of illustrations and suggested demonstrations to guide him.

(k) A library with a variety of supplementary reading material for both teachers and students.

(l) The teacher has a reasonable teaching load, an attractive salary and does not need to take on a second job in order to make a living. He has the opportunity for in-service training consisting, at least in part, of participating in the development of new teaching aids and materials at a well equipped Science Teaching Center.

(m) Some of the newer materials for learning such as films, film-strips, sound-tape, video-tape, audio amplifiers, and computer-assisted instruction.

(n) The teacher is not too slavishly tied to a uniform syllabus.

(o) There are means to cope with the bright as well as with the slower students.

(p) Tests, quizzes and examinations developed with the help of experts are used as tools for learning and not as barriers or merely as a means of classifying students.

(q) A modest work shop where simple repairs on equipment can be made by the teacher or even by the pupils.

(r) A situation where a mood of wonder, an attitude of inquiry and an openness toward questioning on the part of students are encouraged; where learning "begins in wonder and ends in delight".

(s) A teacher with sufficient confidence, based upon adequate mastery of content and methodology to say occasionally, "I don't know", followed by suggestions on how both pupil and teacher may proceed to find the answer.

32. There is no need to catalogue a long and detailed list of what needs improvement in present day science teaching. It is left as an exercise for the questioner to check the points of the previous section asking himself which of these characteristics of science education already exist in his country, in his school district, or in a particular school. There are places in the world where some of these characteristics already exist but no school system today possesses all of them. This is especially true in the less developed areas of the world although the need

for accelerated change is greatest there.

33. Even if science and technology and the world population were static, the task ahead in science course improvement and curriculum reform would be enormous if we wished to change from the existing situation to the ideal one of the future. They are not static, however. Scientific information has been doubling about once every eight years while the total world population has been doubling once every thirty-five years. The growth rate of population of school age in the developing countries is about the same as the rate of growth for scientific knowledge. In both cases there is a multiplication factor of about five hundred within the average life span of a man. Try to imagine, in a less developed country, 500 children in school for every one you see today.

34. It is apparent, therefore, that to be successful, a concerted attack on the problems of science education must be limited in scope and objectives in order to produce significant and noticeable results in a reasonable time. A list of suggested limitations on such a program is given below. No concerted attack should be planned until firm decisions have been made concerning these and/or other proposed limitations.

(a) Plan the program for a fixed period of, say, ten years (The International Science Teaching Years? The International Decade for Science Teaching).

(b) State in operational and measurable terms what the desired outcomes will be.

(c) Limit the program to the basic sciences: mathematics, physics, chemistry, biology (and possibily the sciences of earth and/or space).

(d) The applications of science are important. Decide in advance, nevertheless, that initially there will not be a separate program on technology but plan to improve technical and technological education by giving many practical examples using common objects like the bicycle and the telephone in teaching the basic sciences. In a primitive area a physics course, for example, can and should - without losing sophistication and rigor - have a practical orientation. The underlying premise is that the basic sciences provide the firm foundation upon which to build the successful education of high level cadres of scientists, engineers and technologists as well as of a general public imbued with an understanding of and an appreciation of the spirit of science.

(e) Work within the context of an in-school program. (Despite the great importance of programs for out-of-school implantation and popularization of science, control over all the variables is apt to be easier in an in-school situation.)

(f) Choose only one level of the school system to begin with. We recommend the secondary or pre-university level. The greatest experience in existing course improvement projects is at this level. It is high enough to attract the much needed help of university scientists and to serve as a base for improved university teaching. It is, in some of the less developed countries, also the highest level to be reached for many years to come for the great bulk of primary school teachers who will teach the science and the spirit of science to the children of the future. It can thus point the way for future developments in both university and elementary science teaching reform. It should be stressed that, as far as concepts are concerned, there are no rigid boundaries separating elementary from secondary curricula. Some of the excellent introductory physical science material (pre-secondary) now being produced may very well fit secondary school needs in some countries.

(g) Focus primarily, but not exclusively, on the needs of the less developed countries. There are programs (e.g. the so-called "poverty programs") in advanced countries which could benefit from the new science teaching materials invented and developed in the less developed countries. It would provide the less developed countries a tremendous morale boost if their products were used this way, and it might even help them to develop an education industry.

(h) Stress quality rather than quantity. The emphasis should be on improvement. A significant increase in quality is less costly than a doubling of the existing science teaching system. The cost of running science courses in schools and teacher training colleges (the quantitative problem) for a whole country is many times greater than that of running an activity that will improve significantly the quality (in content and methodology) of science instruction. But this improvement in quality may have significant quantitative implications. If, for example, twice as many students can learn science with the help of new materials, methods and techniques with the same number of teachers it is as if the labor force in the teaching profession had been doubled without quite doubling the cost. If, on top of that, the quality of what is learned by the student is increased in the process, an improvement factor will have been introduced for which there is as yet no numerical yardstick. The trend should be away from authoritarian teaching and rote memorization towards more emphasis on inquiry, experimentation, discovery and a fostering of the spirit of science. This should also help the general public of the future to adapt to an increasingly complex and industrialized civilization.

(i) Start with a program whose first goal is to change the behavior patterns of teachers. (First, of the teachers of teachers and then of the school teachers themselves.) This does not mean that new teaching materials for the pupils will not be developed. On the contrary, the best way to develop the new materials is to permit the teachers to do the necessary research and development under proper guidance and, in the process, learn how to use the new approaches, methods, techniques and materials thus developed. The ultimate goal is, of course, to change the behavior patterns of pupils but that will come about if the behavior patterns of the teachers and the teachers of teachers have been properly changed first and they can if the appropriate learning materials have been made available.

35. A check list is given below of criteria for a concerted program of action within the limitations given above.

(a) The success of the program should be judged in terms of its ultimate relevance to the promotion of the spirit of science. It should strive to develop activities to increase the number and the quality of scientists, engineers and technologists, especially in the developing countries, and, hopefully, it should also increase an awareness of consequences and a sense of social responsibility, consistent with the spirit of science, on the part of men everywhere.

(b) The program should be strongly content- and action-oriented toward innovation, research and development to produce new approaches, methods, techniques and materials for teaching and learning. It should foster continuous improvement in content and methodology and in the behavior patterns of teachers and in the learning behavior patterns of students.

(c) University and research scholars in the fields of science, technology, education and psychology must play leading roles. The projects must be led by teams which include also science teachers and specialists in the development of printed materials, low cost kits of apparatus, self-instructional and testing techniques and in the production of modern communication aids such as films, loops and video-tapes for TV and computer-assisted instruction. Steps should be taken to ensure production and distribution.

(d) As much emphasis should be put on keeping the cost of materials low as on keeping their quality high.

(e) The new materials for science instruction must be part of an integrated program that has considered the continuity of the development of scientific skills and ideas all the way from kindergarten to university. The resulting science syllabi must also be integrated into the overall educational curriculum. Educators are increasingly aware of the fact that the reform of the curriculum should be an integrated, never-ending and continuous process in which the teacher should play an important role. A program of continuous review of content and methodology is envisioned in which the teacher is useful because of his intimate contact with the realities of the classroom and is served by being accorded a more serious professional status through a closer contact with the scholars who direct the program. The continuous rejuvenation of the teacher through personal in-service involvement in actual research and development of the new materials is the key to "rolling reform" of the syllabus and the curriculum and the motivated teacher is the key to the actual use of the new materials in the classroom.

(f) It is strongly suggested that the concerted attack on science teaching improvement should not wait until centers for the improvement of the overall curriculum are established. It is an experimental fact that science education can spearhead the reform needed in the whole curriculum.

(g) The "terminal behavior" of both teachers and pupils at the end of the ten year period should be specified in advance. This is in line with the best thinking in modern management techniques where the methods of systems analysis and operations research are utilized. The final evaluation of the program should be made in terms of the specified objectives but flexibility should be built into the system so that review and modification can take place in order to pursue new profitable avenues of research.

(h) The program should strive to maximize its multiplier effect. The multiplication factor might be measured in terms of the number of teachers, and eventually the number of pupils, whose behavior patterns are changed; in terms of the number of pupils that can be taught effectively by a single teacher utilizing modern techniques and media of communication, and possibly also in terms of the amount of money from other sources which the program can stimulate to be released.

IV. A REVIEW OF ACTIVITIES IN COURSE IMPROVEMENT AND CURRICULUM REFORM IN SCIENCE

Summary: The features that have characterized the course improvement and curriculum reform movements to date are the following. They have: (i) involved scholars from the fields of science, education and psychology as well as teachers and specialists in the different media of communication, (ii) been strongly subject matter and content oriented in the basic sciences, (iii) produced new approaches, methods, techniques and materials for teaching and learning as a result of research, experimentation, development and trial. The trends include (i) a growing interest in the learning process, (ii) the continuous upgrading of teachers through in-service courses and preferably through direct involvement in the research and development activities, (iii) a tendency to descend to the elementary school level, (iv) a greater awareness that the new materials must be well integrated into the overall curriculum, (v) a greater concern for implementation, and (v) the participation of business and industry in what is now being called "the technology of education".

36. There is a promising trend towards international activities in science education. Several of the specialized agencies of the United Nations including UNESCO, references (2) through (12), whose strongest activities have been in education and science, have programs that involve science education directly or that can benefit from course improvements in science and technology. The United Nations Development Programme (Appendix III, para. 2), for example, has given substantial financial support to projects in vocational training and technical education whose success depends, inpart, on participants well trained in the basic sciences and has supported the creation of teacher training colleges in Africa, each of which has departments in the basic sciences. Regional organizations (13) devoted to economic developments and cooperation have also started programs to improve the teaching of science and technology. Although the flow of information and aid in science education has been from the advanced to the less advanced countries, there is a growing recognition that experience arising out of the solution of certain problems in the less developed countries may be applicable to similar problems in selected areas of the advanced countries. The time seems ripe, therefore, for a substantial, cooperative, international effort to improve science education.

37. Although the course improvement and curriculum reform movement in science of which we speak is only about fifteen years old already more than one hundred million dollars of national and international funds have been spent on it. It represents an upward discontinuity devoted to improvement in science education and is not to be confused with the normal and continuous expansion of national science educational services whose total budget is much greater than the figure quoted above. A check list of some of the important characteristics of this movement is given below. It may be used to decide whether an expansion in science education services in a country is due to the new wave of reform activities whose main aim is to improve the quality of science education or whether it is simply due to the normal increments needed to cope with the quantitative increase in enrollments.

38. We will deal first with the general types of activities that have characterized the movement to date. We will then discuss trends with a view of analyzing the shortcomings that must be taken into account before an international program is planned.

39. Characteristics. Here are some of the characteristics of the movement for reform in science education as it has developed to date:

(a) Scholars have been actively involved as leaders and participants in the movement. These have included at least ten Nobel Prize winners in science. Many scientists of all levels have left their classrooms and laboratories, some on a full-time basis, to devote themselves to the development of new ideas and new materials for science teaching. The work has been the result of large team efforts.

(b) Considering the leadership exercised by scientists it is not surprising that subject matter has been the core of the programs which the scholars have infused with contemporary knowledge and viewpoints (13),(14). The programs have been strongly content centered. They have begun with the improvement of specific courses. If the total curriculum was considered at all it usually followed rather than preceded course improvement. The scientists have suggested what to teach and how to teach it on the basis of their intimate contact with contemporary research in their fields.

(c) In spite of the great needs for programs in activities such as the public understanding of science, the popularization and implantation of science among the general populace and especially in children, science clubs and museums and holiday science lectures, the reform movement has started with school science rather than with outside activities probably because public money could be obtained more readily for them and partly because a school program could be better controlled and evaluated than an out-of-school activity.

(d) Most of the programs began with the basic sciences; mathematics, physics, chemistry, biology and occasionally the earth and space sciences. (We shall include mathematics whenever we speak of the basic sciences.) Most of them began at the upper secondary level, probably because, for better or for worse, the subjects are often first clearly differentiated from one another at about that level.

(e) Suggestions on <u>what</u> to teach must often be intimately connected with ideas on <u>how</u> to teach it. Methodology, in other words, especially in dealing with new subject matter, is closely related to content. A decision to teach wave optics using microwaves, for example, demands the use of microwave gear. But there is more to the <u>how</u> of teaching than the manipulation of new instruments. So, when coping with the new subject matter, the help of experienced educators and teachers is needed for inventing new ways to teach. A team consisting of scientists, educators, teachers and other specialists often worked together.

(f) In some - but possibly not enough - projects a welcome member of the team was a scholar from another realm - psychology. It was often the experimental psychologist who brought new pedagogical insights to bear on the problem. By demanding a behavioral description of objectives and of the performance expected of the pupil, the psychologist brought a needed emphasis on the importance of <u>learning</u> as the operational "measure of effectiveness" of teaching. By insisting upon learning rather than teaching and by demonstrating that some kinds of learning can be achieved even without a teacher the psychologist brought a ray of hope that, with the help of self-instructional and self-testing devices, the teacher, whose prospects otherwise tended toward a spirally increasing teaching load, might be relieved of some of the time-consuming and routine aspects of his work and gain some time for more creative and human tasks as a teacher.

(g) Projects were designed to depart from authoritarian teaching. They stressed instead a mood of wonder and a spirit of inquiry and discovery.

(h) The immediate and tangible results of the projects were new materials for teaching and learning produced by the team as a result of innovation, research, experimentation, development and testing. The new materials reflected a concern for the use of new approaches, methods, techniques and media.

(i) The new materials (see Appendix I) consisted of textbooks, teacher's guides, student manuals, supplementary reading material - often in the handy form of soft cover pocketbook - inexpensive kits for laboratory and take-home exercises, laboratory manuals, evaluation and examination materials, transparencies for overhead projectors, film strips, long 16mm sound motion picture films, short 8mm motion picture films or "loops" (so-called because the end is tied to the beginning for continuous display in a casette-loaded projector).)
A well integrated set of teaching and learning aids often became a complete "teaching package" for a course or part of a course. Much of the material is designed for auto-instruction and self-testing whether produced in the so-called programmed instruction form or not. The use of video-tape recording and the use of computers to assist in instruction are new enough to be treated later under "trends".

(j) An important activity in many projects is the retraining of teachers and teachers of teachers. A good way of assuring the enthusiastic use of the new materials is to have teachers who understand them and feel favorably disposed toward them. A good way of generating such teachers is to involve as many of them as possible in actual research, experimentation and development. A useful but less effective way is to rejuvenate the teachers through six-week in-service courses trying out the new materials. The personal involvement of a teacher, however, in writing a script or shooting a film, in the development of a new kit or in the writing of a programmed learning sequence imparts not only new knowledge of content and methods but new enthusiasm. Different types of projects are illustrated in Appendix II. Notable exceptions to the six-week pattern of in-service training have been the International Working Groups of the UNESCO Pilot Projects in Asia, Africa, Latin America and the Arab States (8), (9), (10), (11) in which teacher-trainers have been creatively occupied in course improvement tasks for an entire school year.

40. <u>Trends</u>. As the science teaching reform movement has grown and spread around the world certain trends have developed which may indicate the direction which future activities may take. As could be expected, the trends usually start in the advanced countries and diffuse to the less developed countries but we may be entering a phase where cooperative international efforts may pay off.

(a) One of the most interesting trends is, indeed, the growing international interest in science education. The advanced countries have started activities to internationalize their programs and the less developed countries seem more eager to receive help on a bilateral, regional and international basis than ever before. Better still, they are interested in using available knowledge for developing their own indigenous solutions to their science education programs.

(b) It is increasingly recognized that one of the best ways to improve teaching and learning in science is to plan for the continuous up-grading of teachers and teacher-trainers through in-service training. It is also admitted that adequate pre-service training of teachers in the use of the new materials and curricula is also very urgent. This presents problems and costs which are much larger quantitatively than those of ordinary in-service training of teachers although if well done would reduce the cost of remedial training.

(c) There is greater emphasis on pre-secondary science teaching. New programs are being developed for grades 7,8,9, and others for the lower grades. There is also a trend in the upward direction - toward the university. The scientists who participate in secondary school reform are often the ones who have become sensitized to the need for reform in university teaching and have started programs to produce new materials at this level.

(d) There is a growing recognition that curriculum reform in other subjects also can benefit from research, experimentation and development work (13), (14). There is a growing demand for consideration of total curricula not only for science but for the total spectrum of school subjects. The term "rolling-reform" is being used to characterize the continuous reform that is made possible by involving the teachers themselves in the spirit and processes of research and development of new ideas and new materials.

(e) The team approach is being used more and more by teachers in the teaching process itself - where several teachers teach a subject or several subjects together, complementing their mutual knowledge and the insights from their separate disciplines. It is easy to conceive of the benefits of this approach in teaching the physics and chemistry of the atom, for example, but experimentation and innovation in team teaching may produce interesting results combining efforts of teachers trained in the physical sciences and in the humanities or the social sciences.

(f) There is a trend toward individualized learning (15), (16), (17). This means learning tailored to fit individual needs - whether they be those of a student with high, medium or low capabilities. This may mean greater use of aids such as film strips, loops or video-tapes which the individual student can turn on as he deems necessary or it may mean the use of time-shared computer-assisted instruction (Appendix I) which, although it seems the least personal because of its dependence on complex electronic gear, has, nevertheless, such great versatility that it can be used to meet the needs of individual students.

(g) There is a growing concern for the proper implementation of programs. Experience has shown that the high quality of an educational material or product is not a sufficient guarantee that it will be used. The materials have to be available in sufficient quantities, the teachers must be capable of and willing to use them. The educational authorities must be willing to support them financially and otherwise. A reversal has taken place and there is now a strong trend to permit the inventors and innovators themselves to take a hand in implementing the programs which they created. New sources of funds for the implementation of reform activities are slowly being tapped.

(h) In the industrial countries there is a growing involvement of business and industry in education (19). In some of these countries the potential for large markets has

has led to combines of important industrial and educational firms to participate in the research and development and, of course, in the eventual large-scale production and distribution of the new materials for teaching. Some of the hardware arising out of these efforts, such as projectors, video-tape machines, teaching machines, computer-assisted instruction devices, etc. will have multiple uses. Hence the involvement of industry in the whole curriculum and not only in science.

41. An international concerted attack should, of course, take full advantage of what has been learned from the running of course improvement activities to date, for example:

(a) Adequate means of international transfer of information on matters of science course improvement must be developed. The good start made by regional organizations and of international organizations such as UNESCO (through its regular programs and with the help of UNDP) must be continued in a way which is more vigorous in quality, in quantity and in speed.

(b) Creative thought must be given to implementation even in the planning stages of course improvement and curriculum reform. All the factors meeded for success have to be foreseen from the start. Thus not only scientists, educators, teachers and specialists but also ministers of education, science inspectors and planning authorities in both science and education must give it their support.

(c) Some form of control may be needed in order to optimize the output of the reform activities. Experimentation might go as far as comparing two or more different schemes, but only to the extent that both claim to have similar objectives.

(d) New institutions have to be devised and built in order to generate the continuous "rolling reform" demanded by the ever-growing body of knowledge and world population. Teachers need to be rejuvenated periodically. Special centers (6) devoted to research, development, innovation and experimentation must be created where the teacher trainers and the teachers can go for periodic upgrading in knowledge and morale.

(e) Finally, of course, new sources of funds must be found for a concerted attack. World banking sources, national sources, foundations, business and industry must be approached to contribute to a cause that may benefit all concerned.

V. SPECIFIC RECOMMENDATIONS FOR A CONCERTED ACTION ON SCIENCE TEACHING IMPROVEMENT IN DEVELOPING COUNTRIES

Summary: For immediate action.

1. A Meeting of Experts to make specific suggestions for promotion, execution and implementation of a ten year program with cost estimates. ($20,000)
2. A meeting of prospective financial contributors to pledge support for a concerted action. ($20,000)
3. Collect data for and publish a revised version of the Report of the International Clearinghouse on Science and Mathematics Curricular Developments in three languages. ($40,000)
4. Establish an International Information Center for Science Teaching. ($3,000,000)

For later action.

5. Support the programs of the Teaching Commissions of the International Scientific Unions in the basic sciences and of IUCTS through grants. ($1,000,000)
6. Extend the scope of the UNESCO Pilot Projects on new approaches to the teaching of the basic sciences in developing countries. ($4,000,000)
7. Publish a brochure concerning the UNESCO Pilot Projects and their extensions, in four languages. ($20,000)

8. Run an international conference and exhibition on new materials for course improvement and curriculum reform in science. ($500,000)

<u>Long range plans.</u>

9. Establish ten permanent National Centers for the Improvement of Science Teaching. ($50,000,000)

10. Establish an International Institute for Research and Development in Science Teaching. ($15,000,000)

Total cost $73,600.000.

Total cost $73,600,000.

42. A program for developing countries is proposed which may also help the advanced countries not only because they are all, to a certain extent, underdeveloped in science education, but because they can benefit from improvements in the developing countries in two ways. First, as we said earlier, new approaches that solve problems in developing countries may be applicable in marginal economic and social areas of the advanced countries. Second, the advanced countries will have to supply many of the leaders for a concerted action. This will require special training programs which will eventually increase the pool of manpower in course improvement and curriculum reform. Experts sent abroad will return from their field assignments with new ideas and skills and possibly sensitized to international needs. Such experts will be needed in the coming days of increased international cooperation when greater emphasis may be placed on a reduction of duplication and on a rationalization of bilateral aid programs, possibly by working through international agencies. Some advanced countries may wish to establish their own national projects patterned after the following program for the developing countries but adapted to their own specific needs.

It is based upon the limitations and criteria developed in section III and has taken into account the experiences of the existing curriculum reform projects mentioned in section IV.

Suggestions for Immediate Action

43. A Meeting of Experts should be held, as soon as possible, under the auspices of UNESCO, with extra budgetary financing, to discuss the ideas arising within the Advisory Committee for Science and Technology applied to Development as a result of this paper, and to make definite proposals for a concerted action. The group of Experts could be strengthened by the addition of representatives from UNESCO, from the Office of the Director for Science and Technology of the U.N., from the United Nations Development Program, from the International Institute for Educational Planning, from international banking organizations and possibly by the addition of observers from other organizations. The objective of the meeting would be to make specific suggestions for promotion, execution and implementation of a ten year program with cost estimates. The deliberations of a meeting which took place in May, 1967 under the auspices of UNESCO may be studied for their possible relevance to such an action (2). (Total number of participants, excluding UNESCO personnel, 25; maximum duration: 5 days; approximate cost: $20,000).

44. Convene a meeting of prospective financial contributors

to a concerted action on science teaching improvement for the purpose of pledging support. (Total number of participants. excluding UNESCO personnel: 25; maximum duration: 5 days; approximate cost: $20,000).

45. With the help of organizations such as the Teaching Commissions of the International Unions and the Interunion Commission on the Teaching of Science (IUCTS) further information should be gathered on course improvement and curriculum reform activities round the world. A good start in this direction has been made by the Division of Science Teaching of UNESCO; but the nearest thing to a summary report of national and international activities in existence is that produced by the International Clearing House on Science and Mathematics Curricular Developments, 1967 (21). Using the principle of strengthening existing nuclei, this report should immediately be translated into French, Spanish and Russian and distributed widely along with a questionnaire to gather information for a revised and enlarged edition needed as a basis for advanced planning of a concerted action. The project could be financed by extra budgetary funds and administered by UNESCO. The actual work of translation and collection of new data especially from countries (including some important ones) not yet represented in the 1967 report could be done under contract. The estimated cost for translation into French, Spanish

and Russian, plus the printing of a total of 8000 copies and producing and processing of a questionnaire would be about $40,000.

46. Establish at the earliest opportunity an International Information Center for Science Teaching where the latest teaching and learning materials in science using new approaches and modern techniques would be exhibited as a working display. The staff would consist of a director, five scientists (mathematics, physics, chemistry, biology and general science), five laboratory assistants, one workshop technician, one audiovisual and film specialist and one specialist in auto-instruction and testing. An immediate task for the staff would be to prepare, in self-instructional form, information on new ideas and new materials for science teaching and learning, for scientists and teachers en route to field assignment. and for other teachers and educators interested in them. By using the most modern of self-instructional devices, the flow of visitors could be handled even if they came at random times and stayed for varying intervals of time. In this way, the visiting teacher or scientist could learn the value of the new techniques and materials by actually manipulating the laboratory equipment, studying the new texts and seeing the new films, all under guidance from the auto-instructional devices and the personal surveillance of the staff. The responsibility of the staff would also include the preparation of continually

improved versions of this information material in several languages and the keeping of apparatus in good and demonstrable working order. The center should be part of UNESCO if possible or if not, at least be near it, in order to complement the work of the Division of Science Teaching of UNESCO. The operational experience picked up in running this Information Center might be invaluable in the future establishment of a full-fledged International Institute for Research and Development in science teaching. (para. 52) UNESCO has acquired operational experience along these lines by running two small briefing rooms where documents, films and equipment have been gathered from selected countries; but these are inadequate to the global task. It is felt that everyone concerned with course improvement and curriculum reform in science round the world could benefit from the existence of an excellent multi-media center doing the job of both a clearing house and a briefing center. The Information Center should not be confused with the International Institute proposed below (para. 52). The estimated staff and equipment costs of the Information Center alone would be about $3,000,000 for the ten year period.

Suggestions for Later Action

47. Each of the Teaching Commissions of the International Unions and IUCTS has its own program of action. Some consideration may be given to the possibility of grants-in-aid to them through UNESCO to carry out projects which are in line with the criteria

of the concerted action. This would cost a total of about $1,000,000 over a ten year period.

48. Extend the scope of the UNESCO Pilot Projects in the Basic Sciences by running new projects - possibly called Regional One-Year Science Curriculum Reform Projects - in each of the regions (Asia, Africa, Latin America, Arab States) utilizing, in each case, ideas generated in one of the other projects. For example, the physics of light course produced in Spanish and Portuguese should be translated into English and French and used in Asia where the Chemistry Pilot Project was centered. The Asian physics project could begin by studying and testing the physics of light materials produced in Latin America, but should then proceed to generate its own materials in another important area of physics. Every effort should also be made to make the best possible use of the newest materials from the curriculum reform movements in the advanced countries. The minimum activity could consist of a new Science Curriculum Reform Project in chemistry in Latin America, one in physics in Asia and one in chemistry or physics in Africa, all starting in 1969. There should be provisions for translation of new materials so that the final product appears, preferably simultaneously, in English, French, Spanish and Russian. The total cost for these three one-year projects would be about $1,000,000 (In the Arab States the International Working Group of the Mathematics Pilot Project

will be just getting under way.) If it were possible to have physics, chemistry and biology in each of the four regions, the cost would be about $4,000,000.

49. In running Pilot Projects UNESCO has learned how to take full advantage of the great wealth of material already in existence in the advanced countries, but has insisted that it be used as the basis of local thinking and development of indigenous resources, especially in the form of kits, texts and loops. These projects should continue to serve the purpose of information, catalysis and stimulation of interest in reform but, most important, they should demonstrate operationally that local development of ideas and materials for curriculum reform is possible in less developed areas. These projects also serve the purpose of a talent search for the gifted scientists, teachers and educators needed for the implementation of future programs. Perhaps even more important, these projects can serve as the nuclei of future permanent national institutions devoted to course improvement and curriculum reform in the sciences (para. 51). The program should start with the publication of a special brochure summarizing the philosophy, modus operandi, accomplishments to date and future plans of this series of projects (cost of production in four languages, total 8000 copies, about $20,000).

50. Some consideration might be given to the possibility of running a large international conference on new materials for

course improvement and curriculum reform in science. It would be expensive and difficult to run. Its effectiveness might not be as great as that of the very direct type of action suggested so far and certainly it should not be given the first priority in time. It is conceded, however, that as a means of dramatizing the world-wide importance of a concerted action, a well planned and well-executed conference at the proper time might serve a very useful informational and promotional purpose. It could be the responsibility of the Teaching Commissions of the International Scientific Unions under contract from UNESCO (see paragraph 47). It should occur after the participating countries have had time to produce something they wish to show, otherwise it would be primarily an exhibit of materials from the advanced countries. All the main contributors to the present reform movement should, of course, be represented but an important focus of the conference would be an exhibition of the indigenous materials produced in the developing countries. It could include an international science fair at which selected students from developing countries would exhibit their research projects. It could also have an international exhibition set up by the manufacturers of the most modern equipment and materials for science teabhing at which the public could see films, film-strips and loops, experiment with the low-cost apparatus, try a short self-instructional sequence, experiment with a teaching machine, learn from a computer-assisted instruction scheme, etc. Done well, the conference and exhibition could be a stimulating and exciting activity which provided a dead-line toward which contributors could aim for the production of materials. It should, of course, also have work sessions on specialized topics but, since its purpose would be to display modern ways to learn it would not need to lean on the stereotyped modes of verbal communication still used in conferences where the speaker often reads aloud a paper that has already been distributed. The meetings could center around discussion of the problems brought by participants from the less developed countries. All the newest methods of communication involving the latest advances in optics and electronics should be actually utilized in running the conference and not be simply displayed by technicians who are not teachers. The theme of the exhibition, stated here informally and tentatively, might be: "come and learn something about science the way your children and grandchildren may someday learn". The cost of the Conference (excluding the Exhibition) would be between $250,000 and $500,000. An agreement could be reached with the exhibitors to donate some or all of their materials to UNESCO or to the International Information Center (paragraph 46) or to the International Institute (paragraph 52) if they exist by that time. A much more modest working-group type of conference with about 50 well chosen participants (travel and per diem), ten invited experts (travel, per diem, and fee) and practically no display of materials running for about two weeks would cost about $80,000.

Long Range Plans

51. A long range goal of the concerted action could be the establishment of about three National Centers for the Improvement of Science Teaching (NCIST) in each of the developing regions of the world (Africa, Asia, Latin America, Arab States) with support from international funds. (Similar centers would, of course, also be useful in the more advanced regions of the world.) The object of such a center is spelled out in detail in a UNESCO document (6). It is to provide the institutional means for the continuous improvement and reform of science education through research, development, testing and evaluation of new materials for science teaching and learning. It would be a center for the continuous rejuvenation and upgrading of teachers through a special kind of in-service training in which they become participants in the experimental activities that develop the new ideas and produce the new materials. It would not be a teacher training college but would cater to the needs of the science teachers in the nations by supplying them the resource materials from which the new curricula could be built. Each center would cost between $3 million and $5 million for the first five years after which it would continue to run on national funds. A center could eventually expand its activities to serve a part of or a whole region. It should be attached to a permanent academic institution to insure the participation of scholars in the fields of science, education and psychology. The prestige of the

institution should be high enough to attract staff on leave from other institutions and to lift the morale of the teachers who come there for in-service training. Total cost for ten such centers would be between $30 million and $50 million. Financing could come from UNDP (Special Fund).

52. Establish an International Institute for Research and Development in Science Teaching, whose activities are very similar to those of the national centers but whose participants are the potential directors and staff members of the future National Science Teaching Centers. The shortage of top level experts to man the leading posts of national centers is already apparent. There are, at the moment, not enough international experts in the world in the new approaches, methods and techniques of science teaching and learning. A special Institute is needed to take well trained scientists and educators and give them the opportunity to study the international literature and documentation on the subject and to participate in research and development and in other activities dealing with the new approaches to science teaching and learning. They could, in this way, qualify as international experts to be sent to direct the activities of the national science teaching centers during their first five formative years. The International Institute for Research and Development in Science Teaching might be planned to grow around the International Information Center (see paragraph 46). The staff

of the Information Center might be chosen with this in mind, to be the nucleus of the staff of the International Institute. The cost of the International Institute would run higher than that of a national center; a rough estimate would be about $15,000,000 for the first ten years. If it is "built-on" to the International Information Center, the cost of the whole operation might be reduced to about $16 million for the first ten years. This might be split into as many as five parts; for example: 20% UNDP, 20% international banking sources, 20% foundation sources, 20% UNESCO and 20% from the host government.

53. An early start must be made in the search for sources of support for a concerted action. There are at least 6 sources of funds: (i) The United Nations, its specialized agencies and the organizations closely linked to the execution of its programs such as UNDP; (ii) International banking sources; (iii) Sources of bilateral aid in advanced countries; (iv) Philanthropic foundations; (v) Industrial sources; and (vi) National governmental sources. It should be borne in mind that UNESCO is the international agency whose main responsibility is education and science and that it already has an ongoing program devoted to the aims already expressed as those of the proposed concerted action (2). UNESCO possesses the staff and experience to launch some of the proposed concerted action activities, but lacks sufficient funds and would need more staff to carry a heavier

share of this action. Extra-budgetary funds put at the disposal of the Science Departments of UNESCO might be the first required step.

54. Consideration might be given to the establishment of a special Office within UNESCO (consisting of the staff of what might be called the International Decade for Science Teaching - IDST) to convene the meeting of experts (paragraph 43) and the meeting of prospective financial contributors to a concerted action (paragraph 44). It should have a clear mandate, power to act and a reasonable amount of independence.

55. As an alternative to other methods of funding, a UNESCO Foundation for Modernization of Science Teaching and Learning might be established. It could be run by the staff of IDST (paragraph 54). It could administer grants after the manner of other foundations. This foundation could be responsible for running the International Information Center (paragraph 46) and the International Institute for Research and Development in Science Teaching (paragraph 52) but would not affect the normal operations of the Division of Science Teaching of UNESCO. Administrative details connected with the running of projects could be reduced greatly if grants were given, as is usual in research, by finding competent investigators and giving them a budget and a free hand to run a project with no more than

complete a-posteriori accounting of all activities and funds. A sum of $100 million in the hands of such a foundation could administer with dispatch the total program we have suggested and more. It is a sobering thought that in the area of international science teaching improvement, a sum as large as $1000 million (which is still less than the yearly budget of the office of education in one of the advanced countries), spent over a period of ten years might produce a program so vigorous as to alter the course of history.

APPENDIX I. A REVIEW OF MODERN METHODS, TECHNIQUES AND MATERIALS IN SCIENCE TEACHING IMPROVEMENT

56. What is new in one region may be old in another. We use the word modern here in relation to the needs of the developing countries. Some of the most recent developments in the advanced countries will be treated later under "trends". Their arrival and use in the less developed regions might be accelerated by a concerted attack on the problems of science education.

57. Instead of giving definitions let us give some examples. An example of an old method of teaching is to have the teacher lecture while the student takes notes which he is supposed to memorize. A time-honored technique for evaluating what the student has learned is to give him a written essay-type examination at the end of the course. The oldest materials used for teaching and learning are, probably, blackboard and chalk and the student's slate or notebook. In contrast with these, an example of a modern method of learning is to use the self-instructional tool called "programmed instruction". An example of a modern technique is the use of short, silent, cartridge-loaded 8mm motion picture films to present an experience or an experiment to the student. An example of a modern material is the take-home kit of laboratory equipment with which a student can do an experiment even in his own home. Close analysis of these and other examples would

reveal that methods, techniques, materials and even media are intimately interwoven so that it may be difficult to decide whether one is speaking of one or of the other. The modern trend is toward a greater emphasis on what the student learns rather than on what the teacher says or does.

58. The modern methods, techniques and materials have grown out of a fundamental change in the approaches to teaching and learning. The old approaches were based upon the idea that science consisted of a stable and immutable body of existing facts. The new approaches exemplify better the spirit of science. They stress inquiry on the part of the student. He is led to discover a universe that is constantly changing, never entirely known, but always capable of being investigated.

59. Inasmuch as the material content of a project reflects its aims and methods we will stress materials. We will put emphasis on the types of new materials that can be produced locally in the developing countries. Experience has already shown that it is not enough to import the best products from the advanced countries. They often will not be utilized unless the teachers have been won over to and trained in their use. The best way to do this seems to be to get the teachers themselves involved in the research and development that leads to their production. That is not to say that existing films, texts and kits from abroad

cannot be used to good advantage but that the long range problems of "rolling reform" will not be solved until local teams of scientists and educators produce versions that they are proud to call their own.

60. One of the characteristics of the science curriculum reform movement, now in its second decade, and starting to produce its second generation of teaching aids, is a growing awareness of the importance of creating materials which take into account and seek to preserve and exploit the great variation in individual differences in talents and interests among both teachers and students. This is reflected in the great variety of new teaching aids which are being made available and the flexibility permitted in their use. They supplement one another, having evolved from an integrated approach in their development. We have chosen to discuss as examples only those in the following categories: (i) laboratory, classroom and field equipment, (ii) printed materials (except programmed instruction), (iii) films, loops and other audio visual materials, and (iv) programmed instruction. Some projects have produced animated motion pictures and still others are utilizing computer-assisted instruction. These very new advances will be discussed later under "trends".

61. Laboratory, classroom and field equipment. In the developing countries the greatest weakness in science teaching stems from the

lack of experimental apparatus for use in the school laboratory and in the field. It is conceded that science should begin with observation, measurement and experimentation but often only lip service is given to this idea because commercial laboratory apparatus is expensive and hence unavailable. What the UNESCO Pilot Projects and other regional and international activities have demonstrated is **that laboratory kits whose unit price is low** can often be produced from local materials. Experience in such projects, on the other hand, demonstrated that the research and development that leads to apparatus which is simple and whose ultimate unit price is low is neither easy nor inexpensive. It would be foolish to repeat all the costly development work already done. A good way to start in a less developed country is, therefore, to purchase a complete set of the materials from each of several curriculum projects in several advanced countries (Appendix II) in order to adapt it to local conditions and to the availability of local materials. (A ripple tank, for example, need not have four legs, it can work with three. The legs need not be of aluminum; they can be made of wood or of bamboo). In the UNESCO Pilot Project on the Physics of Light, for example, eight boxes of equipment, each made to sell for about three dollars apiece, were designed and produced in Latin America (by Latin Americans) to do between 16 and 24 experiments in a well integrated course. Similar experiences are expected from other projects in other sciences and in other geographical areas.

(Appendix II). The need for laboratory equipment is highest in physics and diminishes as we pass progressively to chemistry, biology (where field equipment is necessary) and mathematics, in that order, but the great learning opportunities associated with the actual manipulation of equipment used for observation and measurement should be given high priority, especially in developing countries.

62. Printed materials. Bertrand Russell once said that when the printing press was invented lectures became obsolete. This is an exaggeration but it makes the important point that information can often be transmitted better and more accurately by the printed than by the spoken word. Printed materials are among the most important of the teaching aids. They can help relieve the teacher of some of the responsibility of transmitting information. Armed with them the teacher can spend more time in dealing with the different individual needs of his students. The printed word has exerted and will continue to exert great influence. For this reason it is essential that modern printed materials in science be up-to-date, accurate, well illustrated and interesting. They should not be created in isolation from the other teaching aids. We are not advocating simply the writing of more books. We are suggesting that they be produced by the same team that plans the totality of the teaching aids for a course.

(a) Textbooks

Teams of scholars in science and education should be formed in the developing countries to write the new textbooks adopted to local needs based upon the best that curriculum reform groups in the advanced countries have been able to produce. The basic choice of content and organization of subject matter that goes into the textbook usually serves as a guide for all the other teaching and learning aids that may be produced. The trainers of teachers, some teachers and even some students should be involved in the writing process in order to ensure that the final product is really understandable to the pupil. The integration of the other teaching aids is best effected by planning them at the same time that the textbook is being planned and organized. In some projects the student textbook is called a Study Guide because it contains not only the subject matter of the course but detailed instructions on how to go about learning it. Since learning entails more than rote memorization of facts the student needs worked out examples, short self-testing sequences and suggestions of other activities, some to be performed after school, which will assist in understanding the basic principles. A textbook written fifty years ago may have had very few illustrations, few biographical references, possibly no summaries at the end of each chapter, no questions, no problems and certainly no self-testing sequences. Some of them did not even have an index. A modern combination text and Study Guide has all of this and more of what is needed to create the desired situation in which learning can take place.

(b) Teacher's Guide

In many projects (See Appendix II) the special book called a Teacher's Guide to help the teacher is even more voluminous than the textbook itself. It is full of detailed suggestions for the teacher on how to put across the points in the course. It contains an analysis of the problems and questions in the text and details of classroom demonstrations to illustrate important points. Since there is to be a heavy emphasis on laboratory experience, the Teacher's Guide helps the teacher understand the significance of the experiments. It gives suggestions for pre-laboratory and post-laboratory discussions and assists in planning the course and tests of achievement. The guide should not replace actual experimentation on the part of the teacher. It should, instead, induce him to be prepared for the students' questions by anticipating the kind of responses needed for some of them. An important part of some guides deals with tests to evaluate the student's knowledge. Sample tests are given which may be used as they are or as illustrations of how to make up a good test.

(c) Supplemental Reading Material

In some cases an interesting topic in the textbook can be treated in an expanded form in a separate paper-bound booklet or in a Reader that contains a set of supplementary readings for browsing. Often the Reader contains short articles written by experts with a facility for simple and clear exposition. These selections are from the writings of scientists or of non-scientists who have been affected by the developments of science. They are short expositions that can be read with profit to develop in the student a feeling that science is a creative and cultural activity in its own right. Many of them have been translated from their original language into other languages. They are easily adapted to a variety of courses other than the one for which they were created.

(d) A Laboratory Guide for the Student

The laboratory equipment mentioned earlier is designed to be used in experiments which are outlined in detail either in the Teacher's Guide or elsewhere. The student has his own Laboratory Guide which leads him on in the process of discovery without resorting to "cook-book" type of instructions. It contains a brief description of the experiment with cautions for the proper use of the equipment and suggestions for further inquiry. The tendency now is to include more exercises than can be done within the time span of the course so that the teacher may choose from them those which he finds most interesting and instructive (15). The ideal would be to allow enough freedom and choice for the teacher so that he feels that he is designing his own course using some or all of the course components put at his disposal. In some cases the laboratory guide has been written in programmed instruction form.

63. Films, loops and other audio and visual materials. We shall not repeat here the arguments in favor of audio and visual aids. We assume that they are known and accepted. Nor will we give a comprehensive review of the status of the art. We will, instead, select some science teaching activities in this realm which show particular promise for actual production in the developing countries. Experience has shown that the benefits are of two kinds. The end product can, of course, be used in classroom teaching but the involvement of teachers in the actual planning and shooting of films forces them to learn the content in a fundamental way and predisposes them toward the use of the materials.

(a) Slides and film-strips. Probably the least expensive of the very effective modern visual aids is the photographic film transparency designed for projection. Mounted in a rigid rectangular mount it is called a slide. A series of still pictures on a roll of film is called a film-strip. The most universally used size is the single-frame of standard 35mm motion picture film (24mm x 35mm) although the trend is toward smaller sizes. Black and white film is the least expensive but in slides or film strips where the total amount of film used at one time is very small (20 frames require only 48cm or about 20 inches of film), the higher cost of color is not prohibitive. Cameras and projectors for 35mm film are almost universally available. A camera may cost between $25 and $250 depending upon the complexity of the optical and mechanical components. Projectors cost between $30 and $300. The cost is influenced by the power of the lamp and the sophistication of the optical and cooling systems.

The potential audience that may be reached by slides or film strips can be judged by noting that the projected image seen in the normal motion picture theatre originates in a single frame of the same kind of 35mm film as that used in slides and film-strips. The considerably lower power of the lamp used in the classroom projector limits the reflecting screen size to about 1.2m x 1.7m when projected in a darkened room. (Some striking new developments in screen design may permit projection without darkening of the room.) By using rear projection, however, through a translucent screen to produce a picture whose dimensions are approximately 24cm x 35cm (comparable to the size of a TV screen) the image is so bright that the room does not have to be darkened. Operating in a normally lit or only partially darkened room has many advantages in a teaching situation.

Anything that can be photographed in color or black-and-white can be projected as a slide or as a film strip. Charts, graphs, drawings, paintings, and, of course, real objects can be photographed for projection. The film-strip can present a sequence of closely related pictures which, combined with commentary from the teacher (or from a tape or disc recording) provides a fairly complete coverage for a topic.

There are many film strips on many science subjects already available commercially but what we are advocating here is the actual production of film-strip teaching sequences by science teaching research and development centers in the developing countries. There is no need for a large outlay to get started. The real need is for teams of scientists and teachers to choose topics from their curricula that can profit from visual representation and to start shooting, even in an amateur way. The more important content-centered intellectual task must come first, and this is why the scientist must participate in the program. When the techniques of production and utilization have been given priority over content the result has often been disappointing. Without content the technique is void. The combination of scientist and film technician is ideal but the intellectual leadership must be given by the scientist. The project can get started without the technician but it cannot get started without the scientist.

(b) Film loops. Motion pictures are no longer a new medium, but, one of its relatively new offsprings - the short film designed to present a single idea or demonstrate a single phenomenon, sometimes called the single-concept film - may revolutionize the use of films in teaching. Advances in film and projector technology have made it possible to load three to five minutes worth of 8mm motion picture film as a continuous, never ending loop into a cartridge that can be rapidly inserted into or removed from a special projector. As with film strips, the image may be reflected from a screen in a darkened room or, by rear projection, through a translucent screen, it may form an image so bright that little or no darkening is necessary. The greatest advantage which 8mm film loops may have, however, is accessibility. The cost is low, more and more loops are available (22) and their use in the classroom does not require any special experience. The cost of a 3 minute loop is about $15 if bought commercially (and potentially much less if mass produced). The projector costs about $75 (rather than between $400 and $700 for the standard 16mm sound projector). The fact that they are silent requires that the teacher see the film and study the Film Guide in advance so it is also, indirectly, a teacher training device. The projector can be operated even by a child. This permits viewing and reviewing by the student himself.

Film loops have already been produced in the developing countries by teams of scientists, teachers and film specialists in the UNESCO Pilot Projects (8), (10). A catalogue listing about 500 8mm casette-loaded science films has been published (22) and special documents and publications devoted to this new medium and to other aspects of film teaching have begun to appear (23), (24), (25).

Commercial films are usually made first on 16mm or 35mm film and then reduced to 8mm. This is still the best way to produce the basic stock from which copies can be made but small numbers of usable prints can be made using amateur 8mm cameras. As with the film strip we have here a medium that can begin to be exploited with very little in the way of equipment and experience. As usual, the means of communication are being perfected faster than imaginative content to be fed into the medium is being developed. It is easier to produce hardware (cameras and projectors) than software (in this case film loops) that combines content, imagination and relevance to the curriculum.

(c) 16mm sound films. Attempts have also been made to produce science teaching films in developing countries (8). The technical skill can often be found because some of these countries already produce entertainment and advertising films commercially. A sixteen minute sound film of Professional quality is expensive to make. One of the curriculum reform groups with the greatest experience in film making estimates that it costs $1500 per minute of final screen time to produce science teaching films. (The average film runs 15-20 minutes). The projection equipment costs about ten times as much as that needed for 8mm loops and usually a fairly experienced operator (who may be the teacher or a pupil) is required. The room ordinarily must be darkened.

The potential of film teaching is so great, however, that in spite of financial and technical drawbacks most of the curriculum reform groups have produced 16mm sound films (15), (21), (24), (25). They represent a wealth of modern information that can be used in its present form or adapted in the developing countries to spur curriculum reform. A few of the developing countries are in a financial and academic position to enter the field of science teaching film production.

(d) The overhead projector for Transparencies. In this device a large transparency (8 in. x 10 in. or 20 cm x 25 cm) is placed horizontally on a platform. Light goes vertically through it from an intense source below focused by a plastic Fresnel lens. The light continues upward through a projection lens and is then reflected to emerge horizontally over the head of the lecturer. The final image is formed on a white vertical wall or screen. The light is so intense that the room seldom needs to be darkened. The instructor may face the class as he writes with a grease pencil on the transparency producing much the same effect as if he were writing on a blackboard without the disadvantage of having to face away from the class. The transparencies may be obtained commercially in color or in black and white or they may be made by the teacher either by writing on a plastic transparency as he lectures or by preparing them in advance. Tables, graphs, and derivations, for example, can be prepared in advance to be used as needed. It is possible to produce copies of printed matter from books and periodicals by a simple commercial photographic device that produces copies on transparent plastic in a short time, at low cost and with modern methods of development that do not require a dark room. It is a modern counterpart of the blackboard without the attendant chalk dust. Erasures are possible but the transparency may be kept for future reference by the student if necessary. In this respect it differs from the blackboard where, once the message is erased, there is no way of checking on what had been there during a classroom presentation. Already there are teachers even in graduate school who use the overhead projector in preference to the chalkboard at all times (26). They can prepare their illustrations with great care before class or they can utilize the spontaneity of the moment in the classroom to write on the transparency.

It is possible to use overlays consisting of several plastic sheets containing supplementary information which shows through the transparent part of the other overlays. One sheet might have the skeleton, a next the nervous system and another the blood circulation system of an animal, for example.

Still another possibility is to put actual miniature equipment on the platform and demonstrate such things as magnetic fields, waves in a liquid, standing wave patterns, polarization of light experiments in color, surface tension effects on the surface of liquids, the standing waves in the cork dust of a Kundt's tube, electric circuits, etc. Experiments for a whole chemistry course have been designed for projection in a modified and inexpensive version of such a projector.

The intellectual job of inventing new transparencies for science teaching and the actual production of them is something that could easily take place in developing countries even if the projector, for the time being, must be purchased abroad. The cost of projectors ranges from about $100 to $300.

64. Programmed instruction. This technique deserves special mention not so much because it has been widely successful in science teaching - it hasn't, yet - but because it has provided so many useful insights into the problems of teaching and learning. The idea is to break up a learning sequence into small steps of progressive difficulty and induce the learner to climb this staircase of knowledge by rewarding him with his successes (which should be numerous) and providing for his rectification in case

he should go astray. In some forms the program is designed for a "teaching machine" in which the student has to respond to a series of questions in some active way such as making a mark or punching a button. In one version he may not proceed to a certain question until he answered the previous one successfully. In another version a wrong response causes the machine to put him on a side track to pick up the knowledge needed to answer correctly the question he had missed.

The relevance of programmed instruction to the developing countries is not, for the moment, in the production of hardware (like teaching machines) for its implementation but in the benefits of writing the sequences for the programs (the software). In actual fact, the program can be printed in ordinary books and manua manuals which take the place of the machine.

Teachers and teacher trainers can gain from writing programmed instruction material, even if it is never used on a mass scale, for the following reasons. A program is content-centered. You cannot write a program on, say, electricity, without mastering the subject first - you may find yourself reviewing electricity before you can start. Collaboration between the scientist and the specialist who knows the techniques of writing programs can, therefore, be very fruitful, but, as with the making of films, it is easier for a scientist to learn the art of programming than it is for a programming specialist to become a scientist. What is more, the scientist, because of his eagerness to question everything, is capable of suggesting contributions and improvements to programming techniques.

Before writing a program a programmer must (a) specify his target population, (b) specify the terminal behavior expected of it and (c) make a behavioral analysis before writing the program. A good teacher must do the same thing even if he has never used the same terminology. He must, in other words, know the limitations of his students and he must say in advance what he expects of them at the end of the course and then, through a process of systematic questioning and analysis contrive to make all the details of the subject matter explicit. If he states the final objectives only in terms of passing a final examination set by the state, for example, it becomes apparent that teaching for the deeper implications of the spirit of science has eluded him.

Programmed instruction has had its greatest success in the teaching of simple skills but its potential in teaching the basic concepts of science has scarcely been tapped. In science it has been used in several ways: (a) as a remedial device, e.g. to assist students weak in basic subjects, such as elementary mathematics, or in simple skills, such as the use of slide rule; (b) to present material adjunct to the main course by developing in great detail a subject (e.g. vectors) which would otherwise have required a lot of space in the textbook and, (c) as a combination text and laboratory manual to be used along with loops and kits (8), (10), (15).

Trends

65. General The trends summarized below are being set in the advanced countries where the yearly budgets for research, development, demonstration and dissemination of educational media (including those for science) are in some cases over one hundred times greater than they were when the movement for curriculum reform began. They merit examination because some of the future activities in the developing countries will surely bear their stamp. The most important trend is to focus more sharply on the needs of the individual student and to measure the success or failure of programs on the basis of what the student really learns; hence a growing interest in the learning process itself More and more aids are being developed for the teacher and he will be judged not so much by his brilliance as a lecturer, for example, as by his ability to manage properly all the new learning resources (optical, electronic and other) at his command. He will be judged, then, at last, by his ability to create a situation in which learning can take place. Another general trend is to recognize and exploit individual differences both in teachers and in students and to devise new improvement programs that are flexible enough to cope with diversity. The new aids should liberate the teacher for his humane functions as counselor, guide, and amplifier of the latent enthusiasms of his students. There is also a tendency to involve the innovators of the new programs in their implementations. It makes sense, therefore,

to accept the teacher more and more as a collaborator in curriculum development since it is he who can make it work in the classroom and he will do so if it can be done on his own terms. See references (13) through (19).

66. The Laboratory The conventional laboratory as a place set apart for experimentation is giving way to new ways of grouping all learning facilities to emphasize individual learning. This may mean the use of learning carrels each with all the necessary learning resources or it may mean more flexibility in the classroom so that it may become a laboratory simply by regrouping facilities. The use of inexpensive take-home kits may extend the boundaries of the laboratory all the way to the street and to the home.

67. Printed Materials The greatly reduced cost of photo-reproduction of printed matter by electrostatic and other means and a great increase in the speed of reproduction may have serious influence on the quality and the quantity of printed material available to the teacher and the pupil. It may no longer be "printed" in the conventional sense of requiring a printing press but the final product may be indistinguishable from conventional printing. This should facilitate the trial use of experimental materials. They will look "professional" even in the early trial stages.

68. <u>Audio-visual Materials</u> The trend toward new ways to use electronics for the storage and play-back of audio and visual information continues. It has been possible for some time to record both the sound and the sight signals for a TV program on magnetic tape (video-tape). What is new is that the size and the cost of the equipment has been brought down so that it may be used in the home and in the school. It is possible to record what is in effect a sound motion picture and play it back (sound, sight and all) immediately on a TV receiver. The uses include (i) the use of the video-tape as a live "story board" from which the script for a professional motion picture can be written (ii) the use of video-tape to permit a practice-teacher to see himself in action and plan to improve his style of presentation (iii) the possibility of having students plan, direct and produce a teaching sequence on video-tape for the benefit of their fellow students (and for the tremendous gain in interest which they themselves may experience). It is possible that with widepread amateur use of video-tape, the quality of professional educational TV may rise both because there will exist a back-log of partially trained people to draw from and because the general sensitivity to quality will have been raised. A new device has been recently announced (27) which will convert an ordinary television receiver into the equivalent of a home movie projector and screen. The viewer can play the program of his choice by inserting a cartridge loaded with a special new kind of film into a special play-back unit

which would send audio-visual signals into the antenna of the TV set. A seven inch cartridge could play up to 30 minutes in color or one hour in black and white. The cost of the apparatus will initially be $280 (as compared with home video-taping systems which cost between $700 and $3100). One unit could serve all the TV sets in a whole school. Another device permits recording five different sound tracks on one motion picture film (28). Although originally designed to put multilingual tracks on the same film, the tracks could also be used to explain scientific material at different levels of sophistication simultaneously. One track could be addressed to children, another to laymen, another to high school students, another to practice teachers and so on, who could view the film simultaneously as they listened to different sound tracks through earphones. Another is to permit a student to come back to the film and listen to explanations at progressively higher levels of sophistication. It is accomplished by incorporating five sound tracks instead of one on the edge of a 16mm movie film. Most of the trends are toward miniaturization. The advantages of 35mm film strips are now being extended to a similar 16mm film strip. This brings the cost of film and projection equipment down. When coupled with inexpensive sound recording on tape or disc the system becomes yet another auto-tutor. Occasionally the trend is slightly reversed as in the case of super-8 film which permits a larger picture to be recorded on an 8mm film of new format. The increase in area of the projection image is approximately 50%.

69. Computer-made Movies Animated motion picture films have been successfully made in which all details of, for example, computation of a complex motion such as that of a satellite, "drawing" of the picture frame on a TV screen, exposure of the image on photographic film, etc. were directed by a programmed computer. The applications are most numerous in fields like physics (29). The possibilities are so spectacular that already a conferance on computer made movies has been held. Many realms of animated cinematography now enter the realm of feasibility. A sampler film (30) is available.

70. Programmed Instruction The influence of electronics and the computer is most pronounced in the trends which programmed instruction is taking (16), (17), (18). The "teaching machine" tends now to become a computer. "Computer-assisted-instruction" is the result (31), (32), (33), (34). The apparent paradox is that the huge, impersonal and extremely costly device may actually help in the trend towards individualized instruction because the memory of the device is so extraordinarily large that it can store answers for a very large number of questions. The machine can be "time-shared" by many users simultaneously and, because it works so fast, can actually be servicing many students at one time. Many experimental projects are already working in

the field. As usual, the big problem is going to be to devise and store all the programs which the giant machine is capable of handling. Whatever goes into the storage bin of these machines must be put in there by teams of men. In the case of science teaching, the teams will, as usual, have to include the scientists who are always needed at the content end of any innovation.

71. The Involvement of Industry Education has become a growth industry whose budget is about ten times larger than it was at the end of World War II. Many corporate mergers between the manufacturers of hardware (such as computers and teaching machines) and software (such as books and the programs to be fed into the machines) have taken place (19). The object is clearly to make profits but the hope is that the efficiency of the combine in mass production and mass distribution can make available the new materials for learning at a much reduced cost. This is a distinct possibility, but we should raise a warning signal. If the educators, whose ultimate concern is the development of the learner, are not careful, the hardware people will take the initiative from them and efficiency and standardization (in the interest of profit) may be put on a higher pedestal than "inquiry", "discovery" or "the spirit of science". (A recent advertisement of a large electronics concern whibh has joined forces with a software producer offers an apparatus for finding the focal length of a lens by using a laser. It costs over $500. The

obvious questions are (a) is finding the focal length of a lens an important part of the curriculum and (b) is it worth $500 for a piece of equipment when the focal length can be found by using an ordinary light bulb, a candle or even sunlight?)

APPENDIX II. NATIONAL, REGIONAL AND INTERNATIONAL COURSE IMPROVEMENT AND CURRICULUM REFORM ACTIVITIES IN SCIENCE

National Projects

72. It is not possible to give exhaustive coverage of this topic here. Omissions are due to time limitations. The most complete source of information (413 pages) on national, regional and international projects is the Report of the International Clearinghouse in Science and Mathematics Curricular Developments (21). To give an idea of its coverage we reproduce below one of its indices.

Projects Listed Alphabetically by Geographical Area or International Organizational Title

AFRICA:
- African Mathematics Program
- African Primary Science Program
- School Mathematics Project of East Africa (SMPEA)
- UNESCO Pilot Project on New Approaches and Techniques in Biology Teaching in Africa
- West African Examinations Council "A" Level Chemistry Syllabus

ARGENTINA:
- Department of Educational Television

ASIA:
- UNESCO Pilot Project for Chemistry Teaching in Asia

AUSTRALIA:
- Education Department of South Australia
- Education Department of Victoria Technical Schools' Science Courses, Forms 1-4
- Education Depz

Education Department of Western Australia Experimental Secondary School Mathematics (Years 1-3)
Individual Mathematics Programme
Junior Secondary Science Project (JSSP)
Nuclear Research Foundation High School Science Project
Victoria Department of Education Science Curriculum Project
Victoria Matriculation Chemistry

BRAZIL:
Centro de Ensino de Ciencias de Bahia - CECIBA
Fundacao Brasileira para o Desenvolvimento do Ensino de Ciencias

CANADA:
Alberta Elementary Science Project
Natural Science Program in General Education
Project Mathematique de Sherbrooke, Universite de Sherbrooke

CEYLON:
Biology Curriculum Development Project
CAAS School Biology Project
Chemistry, Curriculum Development Project
Evaluation Research Project
General Science Curriculum Development Project
Mathematics Curriculum Development Project
Physics, Curriculum Development Project

CHILE:
Programa de Profecciemento

COLOMBIA:
Improvement of Science Teaching in Colombia
Production of BSCS Materials Translated and Adapted to the Tropical Environment

CZECHOSLOVAKIA:
Center for Modernization of Mathematics and Physics Teaching

FRANCE:
American School of Paris Physical Science Course
French Ministry of Education

GERMANY:
Institute for the Teaching of Physical Sciences Course
Institut fur Bildungsforschung in der Max-Planck Gesellschaft

GREAT BRITAIN:

England:

Association for Science Education
The Centre for Curriculum Renewal and Educational Development Overseas (CREDO)
Mathematics in Education and Industry (M.E.I.)
The Midlands Mathematical Experiment (M.M.E.)
Nuffield A-Level Biology Project
Nuffield Biology Project
Nuffield Foundation Combined Science Project
Nuffield Junior Science Teaching Project
Nuffield Mathematics Teaching Project
Nuffield O-Level Physics Teaching Project
Nuffield Physical Science Course
Pilot Development Project in Applied Science and Technology
Psychology and Mathematics Project
School Mathematics Project (SMP)
The Schools Council
Shropshire Mathematics Experiment (SME)
St. Dunstan's College Mathematics Syllabus

Scotland:

Alternative Syllabuses in Physics and Chemistry for Secondary Schools

Wales:

Swansea Scheme

HONDURAS:

Ensenanza de ciencias

HUNGARY:

Curriculum Project for Special Classes in Chemistry and Physics (Biology), Secondary School, Fourth Grade
OPI Mathematical Reform Project

INDIA:

Experimental Project on Teaching of Science and Mathematics at the Middle School Stage
National Science Talent Search Scheme (NSTS)

IRAQ:

Model Primary School Science Program

ISRAEL:

Adaptation of the BSCS Yellow Version for Use in High Schools in Israel
Experimental Chemistry Programme for Secondary Schools
Study of New Approaches of Teaching Elementary Science
The Teaching of Mathematics in High Schools

ITALY:

Project for a Modern Teaching of Chemistry in Secondary Schools

Project for a Modern Teaching of Mathematics in Secondary Schools

PSSC Pilot Experiment

JAMAICA:

Physics and Mathematics Centre

JAPAN:

Adaptation of BSCS High School Materials into Japanese

The Conference of Science Education Study in Osaka, Japan (CSES)

General Chemistry Course Plan Based on Concepts of Energy and Structure

University of Tokyo Engineering Education Curriculum

KOREA:

Elementary Science Textbook Editing Project

New Science Curriculum Study Project

NSF:

List of Translations and Adaptations of Instructional Materials for Other Countries. References (35) through (40).

OAS:

Inter-American Program for Improvement of Science Teaching Project 212 (PIMEC)

OECD:

New Thinking in School Science Series

PAKISTAN:

East Pakistan Educational Equipment Development Bureau

West Pakistan Educational Equipment Technical Assistance Center

PAPUA AND NEW GUINEA:

Department of Education, Territory of Papua New Guinea Secondary Schools Mathematics Course, Forms 1-4

Department of Education, Territory of Papua and New Guinea Secondary Science Course, Forms 1-4

PERU:

Instituto Para la Promocion de la Ensenanza de la Biologia

Instituto Para la Promocionde la Ensenanza de las Matematicas

PHILIPPINES:

- Bureau of Public Schools - Peace Corps/Philippines Elementary Science and Mathematics Curriculum Development Project
- National Science Development Board - Bureau of Public Schools - Peace Corps/Philippines - University of the Philippines Secondary Science and Mathematics Aides Project
- Notre Dame Educational Association Science and Mathematics Program
- Science Teaching Center, University of the Philippines

PORTUGAL:

- Modernization of the Teaching of Mathematics in Secondary Schools
- Project for a Modern Teaching of Chemistry in Secondary Schools

SCANDINAVIA:

- The Nordic Committee for the Modernizing of School Mathematics
- The Scandinavian Physics Project for the Modernizing of the High School Physics
- The Special Project STP-5/SP Scandinavia for Pilot Courses in Chemistry

SPAIN:

- Canary Islands Mathematics Project (CIMP)

TRINIDAD:

- Structural Material for Teaching Math to Infants; Mathematics for Infants; New Ideas in Math for Children

TURKEY:

- Mobile Units for Science Teaching
- Turkish Ministry of Education National Science Lise Project

UNESCO:

- Ensenanza de Ciencias
- Pilot Project for the Improvement of Mathematics Teaching in the Arab States
- UNESCO Pilot Project on New Approaches and Techniques in Biology Teaching in Africa
- UNESCO Pilot Project for Chemistry Teaching in Asia

UNITED STATES:

This entry is not printed here because it lists 90 projects.
Some of the best known of these are:

- Physical Science Study Committee Physics Course (PSSC)
- Harvard Project Physics (HPP)
- Chemical Bond Approach (CBA)
- Chemical Education Material Study (CHEM)
- Biological Sciences Curriculum Study (BSCS)

School Mathematics Study Group (SMSG)
University of Illinois Committee on School Mathematics (UICSM)
Further information on these and other United States projects may be found in referances (35) through (40).

73. The Report of the International Clearinghouse does not contain information on many countries. For this reason complete internationalization and translation of this report through UNESCO is given the highest priority in the list of specific recommendations in section V.

74. Special mention should be made of the Nuffield Foundation Science Teaching Projects in Physics, Chemistry and Biology because they stress the indigenous production of low cost materials from blue prints made available by them (41), (42).

75. A serious attempt to break down the barriers between the basic sciences has resulted in a text entitled "Science for High School Students" produced by the Nuclear Research Foundation of the University of Sydney, New South Wales, Australia (43).

76. Some additional information on national programs for the improvement of secondary school science teaching may be found in UNESCO publications (44), (45).

Regional Activities

77. UNESCO has Regional Science Corporation offices in Latin

America (Montevideo), the Arab States (Cairo), Africa (Nairobi) and Asia (Djakarta) under the Departments of Science and separate Regional offices for Education in the same regions under the Departments of Education. The regional UNESCO programs dealing with the new approaches, methods, techniques and materials in science education are carried out with the collaboration of these offices. The bulletins put out by them summarize scientific and educational statistics and science education acitvities of the region. They are available from UNESCO, Paris 7, France.

78. The Organization for Economic Co-operation and Development (OECD) has organized regional programs to study and develop improved methods for teaching science. It has held conferences and issued series of publications (13), (47). It has also produced a Catalogue of 8mm Cassette Loaded Science Films (22).

79. Project 212, the Inter-American Program for Improvement of Science Teaching (PIMEC), supported by the Organization of American States, is another example of a regional activity for improvement of the teaching of the basic sciences (mathematics, physics, chemistry and biology). Information may be obtained from Unit of Education and Research, Department of Scientific Affairs, Pan American Union, Washington D.C. 20006.

80. The African Education Program of the Education Development Center, Inc. may be cited as a special example of a partnership between African, American and British educators to introduce new methods and materials in mathematics and the sciences to transitional African nations. For information write to Education Development Center, Inc., 55 chapel Street, Newton, Massachusetts, 02158, U.S.A.

International Projects

81. Most of the activities of the Division of Science Teaching and some of the activities of the Education Departments of UNESCO are international programs related to the improvement of the teaching of the basic sciences. Those that deal with the development of new approaches, methods, techniques and materials for secondary school use are called Pilot Projects. Each project is regionalbbut international utilization of their outputs is planned. To date, four projects have been started and are in different stages of development: Physics in Latin America, Chemistry in Asia, Biology in Africa and Mathematics in the Arab States. Documentation on each of these is available (8), (9), (10), (11). A project begins with the establishment of National Study Groups in the region. These are supplied by UNESCO with books and documents from curriculum reform groups for about a year in preparation for the International Working Group (IWG). The IWG lasts a school year and accepts science professors from

the universities and teacher-training colleges of the region as participants to adapt existing materials and to do research and development on others suited to local needs. As as example of the output, the Physics Project produced 1000 copies of five text and laboratory manuals in programmed instruction form, 300 prototypes of 8 different kits of laboratory material and 50 copies of each of the films which included 11 short casette-loaded 8mm loops and one long, sound, 16mm film. At the conclusion of the International Working Group, the materials are taken by the participants to their National Study Groups for further trial, evaluation and improvement and, hopefully, to stimulate the development of other new materials. The National Study Groups also have the potential of developing into National Science Teaching Centers if they can receive the support of national and international sources of funds (para. 51).

82. Each of the International Scientific Unions in the basic sciences has a teaching commission whose function is to give international support to science teaching improvement through activities of their own and by giving intellectual support and guidance to the programs of UNESCO. Information concerning their activities may be obtained from the following:

(i) International Commission on Physics Education of the
International Union of Pure and Applied Physics
Secretary, Dr. William C. Kelly
National Research Council

2101 Constitution Avenue

Washington D.C. 20418, U.S.A.

(ii) Committee on Teaching of Chemistry

Secretary, D. G. Chisman

The British Council, Albion House

59 New Oxford Street

London WC1, England

(iii) International Commission of Mathematical Instruction (ICMI)

of the International Mathematical Union (IMU)

Chairman, Professor Dr. H. Frendenthal

Boothstraat 1c

Utrecht, Netherlands

(iv) Teaching Commission of the International Union of

Biological Sciences (IUBS)

President of IUBS, M. le Professeur P. Chonard

Professeur de Physiologie Vegitale a la Sorbonne

1, rue Victor-Cousin

Paris 5, France.

APPENDIX III. THE CONCERN OF THE UNITED NATIONS SPECIALIZED AGENCIES AND OF OTHER INTERNATIONAL ORGANIZATIONS FOR THE IMPROVEMENT OF SCIENCE EDUCATION

The following are summaries, made by the author, of communications received.

83. United Nations Educational, Scientific and Cultural Organization (UNESCO). Activities in science education carried out by the Education and Science Departments of UNESCO are summarized in references (2) through (12). The Division of Science Teaching of the Department for the Advancement of Science has overall responsibility for determining science teaching policy within UNESCO (2) and for operational programs dealing specifically with the improvement of the teaching of science. Among these are the Pilot Projects on new approaches to the teaching of Physics (8), Chemistry (10), Biology (11), and Mathematics (9). The concern for improvement, especially through new techniques, methods and materials is expressed in references (3), (4) and (5). A proposal for reform in science education through the establishment of Science Teaching Improvement Centres is given in (6).

84. United Nations Development Programme (UNDP). UNDP has provided assistance to many projects in the fields of vocational

training and technical education. It has experienced difficulties in the execution of many of these projects because of the insufficient preparation which students have in the basic sciences and becuase of their meager acquaintance with the scientific approach to the solution of problems. UNDP has also assisted more than twenty-five secondary teacher training projects, most of which have a science teaching component. This has alerted them to the low level of the quality of science teaching prevalent in many developing countries. In analyzing the causes of their difficulties in execution of projects UNDP cites: (i) lack of competent science teachers, (ii) lack of facilities for science teaching, (iii) lack of textbooks, (iv) wrong approaches and inadequate methods in science teaching, (v) wrong objectives of science teaching in secondary schools. UNDP has had to take palliative measures such as introducing preparatory years, special classes and tutorials in science, to adapt curricula and syllabi and has also had to supply its own experts in the basic sciences in about half of all its technical training projects.

85. Food and Agriculture Organization (FAO). There can be no possible doubt that improved teaching of basic sciences in the school system would make an important contribution to more effective agricultural education and training. At present in many countries and at nearly all levels of training a considerable proportion of the time-table in the initial year of most

agricultural courses is taken up in the teaching of basic science as a necessary foundation for subsequent teaching of the applied sciences and their implications in such subjects as farm management, crop and animal husbandry, etc. It is a constant preoccupation of teachers in the fields of food and agriculture to select what they should teach in fields which inevitably involve a very wide range of academic disciplines. In such a situation it can be stated that the better the candidates are equipped by a sound general education and a good foundation in the basic sciences, the more useful and effective their agricultural education and training will be.

Much of the technical training in food and agriculture involves problems which are similar to those in the basic sciences (e.g. the need for a rapid and effective visual means of illustrating an important principle). It is, therefore, likely that advances in the use of new media and new techniques, such as programmed instruction, will have important practical applications in agricultural education and training as well as in agricultural extension work amongst farmers and the rural community.

86. World Health Organization (WHO). The shortage of candidates for medical studies in many developing countries is mainly due to the scarcity of secondary schools. Furthermore, the high rate of failure of the medical students seems to be due to their

insufficient preparation in the basic sciences. This could be overcome by intensified action by UNESCO in the development of secondary education and the revision of the curriculum content, particularly as regards the sciences and mathematics.

Another area which is most appropriate for concerted action is the establishment of an international centre for training university teachers in educational research and development. The necessity of establishing such a centre for medical teachers has recently been recognized and recommended by an expert committee convened by WHO on the training and preparation of teachers for medical schools with special regard to the needs of developing countries. The establishment of such a centre could best materialize through concerted action by interested United Nations agencies.

WHO has been active in the field of medical education (49), (50), in the use of audio visual teaching aids in medical education (51), (52), (53), (54), in teaching methods, techniques and materials effective in medical education (55), (56), (57) and in the use of radio, films and television teaching (58).

WHO has set up three International Malaria Eradication Training Centres, in the various regions, and in addition assists a further eight national centres in terms of staffing and supplies. Under the guidance of Headquarters, a start has recently been made in the large-scale production of slides, loops and overhead projectuals related to the teaching of techniques used in the eradication of malaria, and for the illustration of case studies. Headquarters has begun the distribution of these slides, films, projectuals and other aids (such as colored charts and diagrams) to all WHO-assisted training centres for the instruction of malaria campaign personnel. Blood slides, sections and other aids for teaching purposes, prepared by experienced WHO Malaria Eradication Training Centre staff, are likewise distributed, free of charge, by Headquarters to national training institutions, universities and training centres all over the world, including public health centres in Europe.

87. International Labor Organisation (ILO). Efficient teaching of basic sciences already at an early stage in the education of children is a basic requirement for subsequent vocational training. Both semi-skilled workers and craftsmen need that fundamental understanding for the basic laws of physics and biology, the properties of common raw materials, the techniques of measuring and the need for exactitude which modern courses in the basic sciences aim at providing.

The development of new techniques of basic science teaching is important also as a complement to practical instruction in school workshops, training centres and on the job, in related instruction courses for apprentices and in the further training of adult workers for updating their knowledge of the job and for promotion as supervisors or technicians.

It is often noted that workers recruited from rural areas and poor urban populations, who have suffered from insufficient or unduly formal education, find it difficult to adapt themselves to the exigencies of modern industry. It is felt that improved and extended teaching of basic sciences at school and in pre-employment courses may assist them in shortening and alleviating this process of adaptation.

88. International Telecommunication Union (ITU). Engineers sent to the field as experts for ITU could benefit greatly from instruction at a science teaching centre on new methods and techniques of teaching. ITU expressed the hope that UNESCO might help.

89. UNICEF. UNICEF has an annual budget of about $50,000,000 if which over $9,000,000 is currently allocated to education, including a sizeable fraction devoted to science education. UNICEF has no specialized project officers and depends on UNESCO for the technical component of its education projects. UNICEF is concerned about the existence of the traditional boundaries between primary and secondary education, about the possible uses of new media such as radio and television and about the use of new techniques such as programmed instruction and correspondence courses. UNICEF believes that science education projects should, as far as possible, be directed to manufacturing apparatus in situ, to innovation and improvisation in apparatus,

to providing for repair and renewal, and to the training and re-training of teachers in the use of modern apparatus associated with modern curricula. Some UNICEF Science Teaching Projects are very large (e.g. Pakistan, $5,000,000).

90. International Atomic Energy Agency (IAEA). The IAEA is interested in the general area of science education in developing countries, particularly in the introduction of nuclear science in the science education programs of these countries. IAEA and UNESCO are in the process of discussing the possibility of holding a joint IAEA/UNESCO panel on the subject. It is also interested in science teaching improvement programs in general. The IAEA supports the idea of the preparation of a general document to contain recommendations for the improvement of scientific education in the developing countries.

91. World Meteorological Organization (WMO). WMO has started a program to establish training centers in developing countires. The first center was in Africa. It was found that it was difficult to get students and that many of those who came had insufficient education in the basic sciences to benefit from the courses.

92. Organization Europeene pour la Recherche Nuclaire (CERN). CERN has a training division one of whose tasks is the in-service training of staff personnel through separate courses in the

basic sciences, especially physics, and in new techniques and developments in nuclear physics. They are experimenting with new methods of teaching, especially programmed instruction. CERN is interested in collaborating with UNESCO to develop new ways to teach nuclear physics.

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