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The Improvement of Science and Mathematics Education in Less Developed Countries

A Status Report with Suggestions for an ISTC Program

Douglas M. Lapp
Bureau for International Development
4044 N. Stuart Street
Arlington, Virginia 22207

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I. INTRODUCTION

During the past two decades, an unprecedented amount of activity has taken place in the development of new approaches to the teaching of pre-college science and mathematics. The United States has been the initiator of much of that activity and by doing so has set new standards for other countries to emulate, either by adapting course materials developed in the United States or by initiating indigenous course improvement projects. American scientists and educators have played an important international role in enabling other countries, particularly the less developed nations, to benefit from the work of American course improvement projects by helping groups located in foreign universities and ministries of education to experiment with the new approaches to the teaching of science and mathematics and to adapt them to local conditions.

However, in recent years American contributions in this area have dwindled. Some of the curriculum centers established in the less developed countries with the help of American financial support and expertise have become isolated, both from science educators in the United States and from educational innovations throughout the rest of the world. There is a need to re-establish communication links with these centers and to set up mechanisms for future collaborative efforts to improve science and mathematics education.

This paper will attempt to provide a rationale for the ISTC to undertake this task by (1) reviewing the progress that has been made in the improvement of science and mathematics education in the United States during the past two decades, (2) assessing the impact of previous efforts to improve the teaching of science and mathematics in less developed countries, and (3) outlining some options which the ISTC might pursue in future programming.

II. A REVIEW OF DEVELOPMENTS IN SCIENCE AND MATHEMATICS EDUCATION IN THE UNITED STATES

The school curriculum reform movement in the United States is usually dated as beginning with the launching of Sputnik and the funding of the Physical Science Study Committee (PSSC) by the National Science Foundation in 1957. Although negotiations concerning possible federal financing of curriculum work in physics had preceded Sputnik, there can be little doubt that public embarassment over the Russian launching of the world's first space probe stimulated prompt action and made funding easier to obtain.

An important mathematics curriculum project, the University of Illinois Committee on School Mathematics (UICSM) initiated its work prior to the PSSC project. The UICSM began work on a small scale with local funding to improve the mathematics taught in Illinois high schools in 1951; its first outside funding was obtained from the Carnegie Foundation in 1956.

The UICSM and PSSC projects were important not only in that they set out to make radical changes in the curriculum of the schools, but also because they established a new developmental model for innovation. Prior to the creation of these projects, the curriculum in the public schools was characterized by a high degree of uniformity, maintained by the economics of textbook production and sales which discouraged any deviation from the status quo. When a new textbook was introduced by a publisher, one could be sure that the basic approach and organization of the subject matter would mirror that of those books that had been successfully marketed in the past. Federal financing for curriculum made it possible for the new projects to experiment with innovative teaching

approaches and new ways of organizing course content.

The developmental model of course construction initiated by the new course improvement projects differed significantly from the process traditionally used by publishers to produce a new textbook. Instead of relying on the talents of an individual author or a few co-authors, the developmental curriculum projects enlisted the aid of a group of research scholars and teachers to develop preliminary drafts of new course materials. These materials were then "trial-taught" in several classrooms to reveal the strengths and weaknesses of the proposed instructional sequences and learning activities. During these trials, the authors of the draft materials could frequently be found in the experimental classrooms, either teaching the class or observing small groups of students so as to obtain their reactions to the lessons. Feedback from such trial classes was then used to improve the course materials; often several cycles of classroom trials and revision were carried out before the new course materials were put into their final form.

The National Survey and Assessment of Instructional Materials conducted by the EPIE Institute in 1976 analyzed the benefits that result from such an "R&D" model of course development:

> R&D-based materials are (not) necessarily the "best" or the "right" materials for every classroom, but...they are more likely to perform as promised when used as directed with an appropriated student population. By R&D-based materials, we refer to materials built upon an empirical data base, as opposed to conventional wisdom, and developed through continuous feedback loops that insure that once-obtained data hold steady over time. A traditionally developed material uses little more than "conventional wisdom,"

that is, usually the manuscript is written by a publishing company's editor, who often is a former teacher, and it receives as "input" critical readings by those who are listed as authors and suggestions from sales representatives and production staff members (EPIE Institute, 1977, p. 22).

A traditional model of textbook development was in general use throughout the world prior to the curriculum reform movement. The shortcomings of such an approach were especially serious in the developing countries, where the textbooks in common use frequently were authored by expatriates who had little or no understanding of the local culture. Although some publishing companies had made efforts to commission the writing of textbooks by indigenous authors, too often the contributions of these local authors were limited to the critique of editorial revisions of books formerly written by expatriates. This situation was further complicated in some countries where the local authors were government officials in a position to influence textbook adoptions.

In the following pages, some of the major course improvement projects which comprised the past two decades of science and mathematics curriculum reform in the United States will be reviewed. It is important to note that the curriculum reform movement was not limited to the United States. Parallel developments occurred in a number of countries and some important cross-fertilization of ideas took place, particularly between educators in England and the United States. However, because American contributions to the improvement of science and mathematics education in developing countries have occurred primarily as an outgrowth of curriculum projects initiated in the United States, a review of the principal American projects is most appropriate to the purposes of this report.

As it will not be possible to review all past projects in this paper, readers desiring further information may wish to consult sources such as Goodlad's review (1966) of the early projects, Grobman's (1970) analysis of the course development process utilized by these projects, or the short project summaries published periodically by the National Science Foundation (1974, 1976). In addition, the recent report of the National Research Council's Panel on School Science (1979) provides a comprehensive review of the current state of pre-college science and mathematics teaching in the United States.

Science Course Improvement Efforts

The first generation of federally-financed science curriculum development projects in the United States focused on improving the pre-college education of students who intended to pursue careers in science and engineering. The initial emphasis was to develop radically new courses for the three main sciences taught in high school: physics, chemistry, and biology. In each case, an attempt was made to bring the course content up to date with the currently available knowledge in science. Even more important, the scientists guiding the development of the new courses decided to abandon the traditional practice of using laboratory experiments to verify principles already learned from lectures or the textbook. Instead, laboratory investigations were to be used to introduce students to new concepts. Laboratory activities were designed to encourage students to think inductively so as to develop a personal understanding of each new concept. The intent of the new courses was thus to help students to begin to think scientifically as well as to provide them with an introduction to the scientific discipline concerned.

The new PSSC physics course abandoned the nineteenth century topics

around which high school physics had previously been organized. Instead, PSSC physics followed a sequence that emphasized the alternative conceptual models that could be used to explain the behavior of matter. Considerable effort went into the design of laboratory experiments and simple apparatus, as well as a teacher's guide, films, and books on special topics. Interest in the new course spread throughout the world and twenty-four translations of the textbook and laboratory guide were made for use in other countries.

Two high school chemistry projects were supported by the National Science Foundation. The first, called the Chemical Bond Approach (CBA), resulted in the development of a course that was highly theoretical and may not have been very suitable for the average student. Perhaps for this reason, the CBA chemistry course was never widely adopted. Work on an alternative NSF-supported high school chemistry course was begun in 1960 by the Chemical Education Material Study (CHEM Study). Like the PSSC physics course, CHEM Study chemistry introduces new concepts through laboratory work. The text and class discussions are designed to help students to tie together ideas introduced in the laboratory by means of the kinetic theory and atomic-molecular bonding relationships. The CHEM Study textbook was widely adopted by school systems in the United States and was translated or adapted for use in over twenty foreign countries.

The Biological Sciences Curriculum Study (BSCS) produced three different alternative courses for high school biology, usually known as the green, yellow, and blue versions. Green version BSCS biology emphasizes the biological community, the yellow version stresses cellular biology, and the blue version focuses on biochemistry and molecular

biology. In all of these BSCS courses, students are expected to spend a considerable amount of time performing laboratory investigations. Materials based on the BSCS biology programs are now in use in over sixty countries.

Following the development of these new courses for the three major disciplines in the high school science curriculum, it became obvious to curriculum planners that a need existed to improve the teaching of science at the junior high school level, so as to help students acquire some basic experimental and mathematical skills and to instill a positive attitude toward scientific inquiry. One of the first efforts at this level resulted in the development of the Introductory Physical Science (IPS) course. In this ninth grade course, students examine the propertie of matter and assemble empirical evidence that leads them to the development of an atomic-molecular model of matter.

The second course designed to replace the general science courses formerly taught at the eighth or ninth grade level is an earth science course developed by the Earth Science Curriculum Project (ESCP). This interdisciplinary course incorporates topics from geology, meteorology, oceanography, and astronomy. Interest in the teaching of earth science has increased in recent years due to world-wide concern about the depletion of fossil fuel reserves and other non-renewable natural resources.

During the mid-1960's, NSF funding resulted in the creation of three major elementary school science projects: Science, A Process Approach, sponsored by the American Association for the Advancement of Science (AAAS); the Science Curriculum Improvement Study (SCIS), and the Elementary Science Study (ESS). The AAAS elementary science program is structured to encourage children to practice fourteen "processes of

science," systematically defined by means of an elaborate hierarchy of behavioral objectives. The SCIS program stresses a predetermined conceptual framework which children are expected to acquire as they examine natural phenomena, manipulate equipment, and record data. The ESS program consists of a series of self-contained science units; each of these units is designed to encourage children to examine a set of related phenomena, make careful observations, formulate their own hypotheses, and carry out experiments to test their hypotheses.

All of these elementary science programs have been widely adapted for use in other countries. The AAAS materials were adapted for use in Argentina and Chile; SCIS materials served as a catalyst for the development of similar programs in Israel, Brazil, and the Philippines; and ESS stimulated the development of the African Primary Science Program.

In the late 1960's and 1970's, science curriculum development projects funded by the federal government turned toward the development of multidisciplinary materials which included an emphasis on the interrelationships between science and society. This trend has been mirrored worldwide in the series of conferences and reports sponsored by UNESCO on the teaching of integrated science (UNESCO, 1971, 1973, 1974, 1977).

Work initiated by the Harvard Project Physics group in 1964 resulted in the development of a high school physics course intended not only for those students planning scientific careers, but also for those who plan to emphasize college studies in the humanities and social sciences and for those who may not intend to go to college. The new course introduces students to a variety of physics topics, including some of the more recent developments, but also stresses the humanistic background of the physical sciences, how physics has contributed to modern technology, and

the social significance of some scientific advances.

At the junior high school level, the Intermediate Science Curriculum Study (ISCS) developed a three-year sequence of science courses designed to allow the pace level of instruction to be adjusted to the interests and abilities of individual students. The seventh and eighth grade ISCS materials are based primarily on physical science themes such as energy, measurement, operational definitions, the composition of matter, and model-building. In the ninth grade course, the student is encouraged to integrate the experience and knowledge gained in the previous two years so as to investigate a diverse set of problems of practical and scientific significance, on topics ranging from geology and weather to genetics and environmental pollution.

The BSCS Human Sciences Program is another multidisciplinary program for the intermediate level. This program is being developed with a special concern for the interests and developmental characteristics of eleven to thirteen year-old adolescents. Content for the Human Sciences course is being drawn from the biological, social, and behavioral sciences. Learning activities are designed to encourage students to seek answers to questions such as, "Why do things change?" and "Why do living things act as they do?"

Because the United States is not currently suffering from a shortage of trained scientists and engineers, there is now less public concern about the training of future scientists than there was at the time of Sputnik. More stress is now being placed on the need to improve the scientific literacy of the general public, in order to help all people to deal more intelligently with the scientific and technological issues that affect their everyday lives. This task will probably be the focus

of most efforts to improve science education in the United States during the next decade.

Efforts to Improve Mathematics Instruction

The mathematics curriculum reform effort in the United States differed from the efforts to develop new courses in the various science disciplines in that most mathematics course improvement projects spanned several years of the K to 12 mathematics curriculum. In American schools, most students take mathematics from kindergarten through at least the second year of high school. Because the development of a mathematics course for any one year depends heavily upon those skills and concepts already mastered by students, changes in course content usually necessitate a reconceptualization of the scope and sequence of the mathematics curriculum extending over several years.

As mentioned earlier, the mathematics reform movement began with the work of the University of Illinois Committee on School Mathematics. The first efforts of the UICSM project resulted in the development of mathematics course materials for grades 9 to 12. This course sequence covered elementary algebra at the ninth grade; plane, coordinate, and solid geometry at the tenth grade; advanced algebra, including mathematical induction and sequences, at the eleventh grade; and the study of functions, including trigonometry, polynomial functions, and complex numbers at the twelfth grade.

Following the development of this program, the UICSM embarked on the development of a two-year junior high school course for underachieving students in grades seven and eight, particularly those characterized as "educationally disadvantaged." The intent was to give such students special attention at the junior high school level so as to prepare them

for a regular ninth-grade algebra course. The UICSM also developed a new two-year sequence of courses in vector geometry for grades 10 to 12.

Like most of the other mathematics curriculum projects, the UICSM developers attempted to present mathematics as a consistent, unified discipline. However, instead of presenting new mathematical ideas as abstract generalizations, the UICSM program materials attempt to lead students to discover important mathematical principles for themselves. UICSM teachers are encouraged to delay the formal verbalization of new concepts until students have had ample opportunities to become thoroughly familiar with a new idea by testing a number of specific examples. The UICSM materials thus share a common pedagogy with many of the science course improvement projects, but different from the other two major mathematics textbook writing projects (SMSG and UMMaP).

The School Mathematics Study Group (SMSG) is probably the best known of the "new mathematics" curriculum improvement programs. Beginning work in 1958 with National Science Foundation support, the SMSG developed sample textbooks for grades K to 12, designed with the intent of providing a model for commercial publishers to emulate.

The School Mathematics Study Group did not espouse any particular theory concerning the way in which children acquire mathematical concepts, but instead chose to base the organization of the new course materials upon the logical structure of mathematics. In the SMSG elementary school program, children were encouraged at an early age to verbalize abstract mathematical concepts involving the language of set theory and the properties of numerical operations. Although students did manipulate numbers, the primary objective of the SMSG materials was to develop an awareness of the formal conceptual structures of mathematics, not to

help children to become "friendly with numbers."

The SMSG textbooks developed for the junior high school years were designed to provide students with an intuitive foundation for high school algebra and geometry. The seventh and eighth grade texts discuss the concept of a number system, examine geometrical relationships, emphasize the structure of arithmetic from an algebraic viewpoint, and provide an introduction to measurement and elementary statistics. Again, as in the elementary program, a premium is placed on the use of precise mathematical definitions and vocabulary, and the development of an appreciation for the rigor of mathematical principles.

The SMSG texts developed for grades 9 through 12 represented a considerable upgrading of the content and approach of traditional high school mathematics courses. For example, the SMSG ninth grade algebra course incorporates an emphasis on number theory as well as algebraic equations. The tenth grade geometry course includes material on solid geometry and analytic geometry as well as plane geometry, and the eleventh grade course encompasses trigonometry, vectors, logarithms, mathematical induction, and complex numbers. The twelfth grade SMSG course includes the study of elementary functions, and an introduction to matrix algebra and the calculus. The high school SMSG courses were thus similar to the initial science course improvement efforts in that they gave cabable high school students an opportunity to be challenged intellectually to the limits of their ability.

The University of Maryland Mathematics Project (UMMaP) was a third textbook development project. With support from the Carnegie Corporation, this project developed mathematics materials for grades seven and eight, plus an experimental course in mathematics for elementary

school teachers. The junior high school school materials place great emphasis on number systems and the elements of mathematical logic, and are based on an elaborate hierarchical structure of learning objectives.

Two important mathematics course improvement projects did not attempt to write textbooks: the Madison Project and the University of Illinois Arithmetic Project. The Madison Project produced a variety of supplementary mathematics materials for grades 2 to 8 that were not intended to replace the existing curriculum in the schools. Instead, the intent was to improve the existing curriculum by introducing students to some of the fundamental ideas of algebra and coordinate geometry, ideas of logic, and problems relating mathematical ideas to some of their applications in physical science. Learning by discovery and the use of "hands-on" materials were characteristics of the Madison Project approach. Project personnel placed a considerable emphasis on the importance of teacher-training activities.

The University of Illinois Arithmetic Project also placed an emphasis on teacher training and developed a variety of supplementary learning activities for use in elementary school classrooms. The Arithmetic Project course materials do not emphasize mathematical rigor or the learning of the precise formal definitions, but instead provide novel learning tasks and networks of problems by which significant mathematical ideas are introduced to children. An extensive series of films were developed by the Arithmetic Project for teacher training purposes.

In recent years, several projects have been funded to investigate the feasibility of providing computer-based or computer-assisted mathematics instruction in elementary schools. The results obtained when

using these programs with small groups of children are intriguing because of the opportunity the computer provides to accommodate the needs of individual students. However, the costs involved in implementing such programs throughout a school system have thus far been prohibitive in the United States and would certainly rule out the use of such an approach in the less developed countries in the near future.

Lessons Learned through Experience with the New Curricula

There can be no question that the curriculum reform movement of the past two decades has had a significant effect on the schools, both those in the United States and abroad. The State of School Science (NRC, 1979) notes that in 1976 over half of the grade 10 to 12 science teachers in the United States were using one or more of the federally-funded science curriculum project materials. At the junior high school level (grades 7 to 9), 33 percent of the science teachers were using federally-funded materials; for elementary school teachers, the figure was approximately 24 percent.

The utilization figures for federally-funded mathematics curriculum materials are considerably lower: 11 percent for grades 7 to 12 and less than 10 percent for the elementary grades. These low usage figures are partly a result of the fact that many of the federally-funded mathematics course materials were developed with the intention of providing models for commercial textbook publishers to emulate. As a result, some teachers may not have associated a textbook they were using with the materials of a specific federally-funded project on which it was based.

However, it is generally agreed that the impact of the mathematics course improvement efforts was greatest at the secondary school level, especially in grades 9 to 12. After examining current teaching practices,

the 1975 report of the National Advisory Committee on Mathematical Education (NACOME) concluded that the most significant changes in mathematics course content and methodology had affected primarily a small sample of the most capable secondary mathematics students. At the elementary school level, the NACOME report concluded that the impact of the "new math" movement was largely cosmetic. Although the topics covered in some elementary school mathematics textbooks were broadened to include some new emphases, very few teachers allocated much time to the teaching of anything other than the computational skills with which they were most comfortable.

The lack of enthusiasm on the part of elementary school teachers for the "new mathematics" was largely due to the formal and abstract approach to mathematics utilized by most of the elementary mathematics textbook development projects. The attempt to present mathematics as it is conceived and structured by academic mathematicians resulted in an abstract approach which included a considerable emphasis on formal definitions and the introduction of some of the language of sets as early as grade one.

Related to this problem was the limited role played by experienced classroom teachers in most of the elementary school mathematics textbook development projects, and the lack of attention generally given to cognitive studies of the development of mathematical abilities in young children. The result was that many of the projects produced materials that most elementary school teachers did not understand nor judge to be appropriate for use with young children. The response of most teachers was to ignore the proposed innovations.

Many cognitive psychologists, scientists, and educators are now stressing that the aim of mathematics instruction should be to help children learn to solve mathematical problems that are meaningful to them and to recognize a mathematical concept in a real-world situation. They emphasize that children can best learn mathematics by using it as a tool with which to explore the world, and they deplore any tendency to force premature abstractions.

Robert Davis, the former director of the Madison Project, has examined this issue at some length in an article in the Journal of Children's Mathematical Behavior. He concludes:

> The highly-convergent teaching of (say) finite fields to 3rd graders leaves us puzzled. There seems to be no exploration, and we normally regard exploration as the essential core of "doing mathematics." This highly-convergent, highly-directed study of sophisticated subjects for which there is no clear need seems to be based on the notion that mathematics is a very large collection of facts and concepts, such as a knowledge of what fields are. Although we have seen this interpretation of mathematics before, it has never had a very compelling appeal...a body of inert concepts does not constitute the main essence of mathematics as a thing you do.
>
> From our value system, the "new formalism" seems incomprehensible, and potentially harmful. If one accepts the principle of not teaching a topic unless that topic gives the student a new ability to do something that he could not do before,..then what valuable new ability does a six-year-old get when he learns the word "set"? We propose further study of this question, but our

present answer is: none that we can identify, and certainly not one that is central and necessary for the process of counting.

Far from giving children a greater ability to solve problems that interest them, the introduction of the language of "sets" serves to create a whole array of new problems, puzzling to children (and teachers), but not of interest to them, problems that do not bring with them commensurate additional power (Davis, 1972, p. 33).

Thus one result of the mathematics curriculum reform movement has been a debate and reconceptualization of the way in which young children should be taught mathematics. However, hindsight suggests another lesson that can be learned from the past two decades of effort: most course development projects in science as well as mathematics suffered from a lack of a systematic approach to program implementation in the schools. In many cases, it appears that government funding agencies have assumed that imaginative and educationally effective course materials would speak for themselves, so that little or no government support would be necessary for their implementation.

However, experience has shown that the educational effectiveness of an innovative program does not provide any guarantee that it will be successfully implemented in the schools. Because most teachers, school administrators, and large school system bureaucracies tend to resist change, specific efforts must be made to address this problem if a new program is to be implemented in the way in which it was conceived.

The report of the National Research Council's Panel on School Science stresses that the experience gained during the past two decades demonstrates that even the best curriculum will not be utilized effectively

unless adequate attention is paid to the following issues:

1. Teachers must be provided opportunities and incentives to acquire the comprehensive training necessary for the successful utilization of the new materials and techniques.

2. Principals should be provided opportunities to gain an understanding of the new programs, for they are key agents for educational change or for maintaining the status quo.

3. New course materials should be introduced in a fashion that encourages the honest exchange of views between teachers and the exponents of curricular innovations.

4. Mechanisms of long-term materials support must be established so that teachers can obtain the instructional materials and apparatus needed for the new courses.

5. Resource personnel should be made available to provide continued expert advice and moral support to teachers and principals when problems arise (NRC, 1979, p. 43).

The need to deal with these issues is not unique to the United States. Problems involving these issues have occured in countries throughout the world, and will be examined in more detail in the next section of this report.

III. An Assessment of Previous Efforts to Improve Science and Mathematics Education in Less Developed Countries

The efforts to reform the mathematics and science curriculum in the United States sparked a considerable amount of similar activity overseas in both the industrialized countries and in the less developed nations. The governments and funding agencies which initiated such efforts in the developing countries placed a high priority on improving the teaching of science and mathematics for several reasons:

1. A good preparation in the fundamentals of science and mathematics is essential for those students who intend to pursue specialized university studies in science and technology.

2. Basic literacy, numeracy, and an understanding of the scientific approach to problem-solving are increasingly coming to be considered as a part of the "knowledge for living" to which every human being is entitled. Many of the new science and mathematics programs are designed to develop rational thinking skills which are needed by all adult citizens.

3. Science education can play a role in helping to solve certain problems of less developed countries, such as the improvement of nutrition and sanitation and the adoption of more effective agricultural practices. The major diseases that afflict people in the less developed countries are not exotic; many could be cured through more effective public health education efforts.

The first of these rationales--the training of future scientists and engineers--was the factor that motivated most of the early efforts to improve science and mathematics instruction in the less developed countries as well as in the industrialized nations. For this reason, most of the

early international education projects funded by technical assistance agencies were focused at the college-preparatory, secondary level. However, in more recent years, attention has been focused on the second and third rationales, with the result that more efforts are now being directed toward the improvement of science and mathematics education at the primary and intermediate levels.

Both through local government funding and with assistance from international organizations, bilateral aid agencies, and private foundations, a considerable variety of projects have been undertaken in the area of science and mathematics education. The most comprehensive description of these projects exists in the eighth, ninth, and tenth Reports of the International Clearinghouse on Science and Mathematics Curricular Developments (Lockard, 1972, 1975, 1977). Robert Maybury's report, Technical Assistance and Innovation in Science Education (1975), contains case studies of five Ford Foundation projects, together with a critical appraisal of the factors that influenced their impact. A UNESCO publication, Innovation in Science Education--Worldwide, written by Albert Baez (1976), former Director of UNESCO's Division of Science Teaching, contains an analysis of past experience and present trends in science education, with special emphasis on the projects assisted by UNESCO. A more recent short review of worldwide trends in science curriculum development can be found in Naama Sabar's article in Science Education (1979).

Innovative efforts in science and mathematics in the less developed countries typically have involved one or more of the following elements: (a) development of new course materials, (b) teacher education efforts, (c) the design and production of instructional materials and equipment, (d) the use of educational technology. In the following section, an effort

will be made to review some important projects in each of these categories so as to determine the lessons that have been learned and to identify the problems that remain to be solved.

The Development of New Course Materials

Direct translations of course materials developed in the U.S

Many of the science and mathematics course materials developed by the large curriculum projects in the United States were translated into other languages for use in foreign countries, including a number of the less developed countries. National Science Foundation records indicate that PSSC Physics was translated into 24 languages and CHEM Study into at least 20. It is not surprising that this should have happened, since most of the pressure leading to the creation of science and mathematics course improvement projects in the less developed countries came from local scientists. These local scientists and the funding agencies which supported many of the projects were attracted to the materials developed in the United States because their content was modern, they placed an emphasis on the study of key principles and concepts instead of the rote memorization of disjointed facts, and they attempted to engage students in some of the processes of scientific problem-solving and inquiry. Undoubtedly, the fact that some leading American scientists had participated in the development of these course materials was also a factor.

However, the effort to transplant course materials designed to fit the culture and conditions which exist in American schools into the very different cultures and school environments which exist in less developed countries resulted in many problems. For example, the early efforts of the Science Education Improvement Project (SEIP) in India consisted of summer institutes for teachers which made extensive use of curriculum

materials developed in the United States which had been reprinted in India by USIS. Although the SEIP summer institutes probably were successful in acquainting Indian teachers with some new teaching approaches and undoubtedly improved their knowledge of science, the teachers were frustrated when they returned to their classrooms because the rigid local syllabus and external examination structure deterred them from implementing most of what they had learned in the summer institutes. In addition, a lack of funds for the purchase of laboratory equipment and supplies made it very difficult for them to utilize the inquiry approach advocated during the summer institutes (NSF Liaison Staff, 1974).

It has been a concern in the United States that some of the projects in the first generation course improvement efforts produced materials that were challenging to the most capable students, but not very appropriate for use with average students or with students who were educationally disadvantaged. The narrow target population of some of the materials, especially in the areas of mathematics and the physical sciences, has sometimes caused problems when direct translations of U.S. materials were made for use in less developed countries.

However, the Science Lycée Project in Turkey supported by the Ford Foundation encountered a different type of mismatch when an attempt was made to introduce the Introductory Physical Science (IPS) materials into the Science Lycée curriculum at the ninth grade level. Maybury (1975) reports that the faculty of the Lycée felt that the IPS materials were "really not very challenging to the children we have at the Science Lycée--(and) inappropriate for the bright children at our school" (p. 131). The IPS materials were eventually adopted for use in the Science Lycee

and were moderately successful. However, when an attempt was made to expand the use of the IPS course into nine other government lycées, the performance of students on achievement tests was only half that of students at the Science Lycée.

Thus it can be seen that the problem of creating course materials that are appropriate to the local situation can be a difficult task, even within a given country. To aid in this task, Maybury proposes five criteria that should be considered before attempting an educational innovation:

1. An innovation should fulfil the value-orientation of those employing it so that, when adopted, it effects that change towards the "better" which they desire.

2. Especially in science education, an innovation should pass the scrutiny of the scientific community in respect to the accuracy and recency of its scientific content as well as the logical coherence of its development of topics.

3. An innovation should possess pedagogical validity, not only utilizing effective techniques but also gearing them to the pupil level for which the innovation is intended.

4. An innovation should slip readily into the school system without clashing violently with constraints of a legal or cultural kind.

5. The costs associated with adopting an innovation should fall within an acceptable range, so that the system can "afford" the innovation (p. 152).

Direct translations of American materials for use in the less developed countries have usually been justified on the basis of the first two criteria, without considering the last two. The issue of whether

the U.S. course materials satisfy the third criterion concerning pedagogical validity and appropriate level continues to generate considerable discussion, both in the less developed nations and within the United States.

Yet, even after recognizing the problems inherent in attempting to make use of direct translations of course materials outside of the cultural context in which they were developed, there are several good reasons why the adaptation of course materials developed in the industrialized nations is often preferable to purely local curriculum development efforts. First, the creation of totally new course materials through a research and development process is a costly venture: NSF investment in the development of the PSSC Physics course amounted to over five million dollars and the three BSCS biology courses cost 10.4 million (NSF, 1975, p. 171). Few of the less developed countries could or should try to replicate such an investment. Second, the recruitment of the professional scientists who worked on the major curriculum projects was a difficult task in the United States, and would be impossible in most less developed countries. Third, once a government commits itself to educational reform it is usually important that results be produced quickly. The most efficient way to produce quick results in curriculum development is to build on the successful efforts that have already been made in other countries. However, it is essential that any borrowed materials be thoroughly adapted to fit local conditions, and used only insofar as they meet local needs.

Local adaptations. Hulda Grobman, in her discussion of the target audiences for which the U.S. course improvement materials were intended, notes that early in its history the BSCS project established a policy of not authorizing direct translations of its materials into other

languages, although it did give permission for adaptations to overseas countries and offered assistance to such adaptation efforts. In the case of biology, the issue was not only that of designing materials to fit the local culture, but also that of making the course content relevant to the local flora and fauna and to the subtleties of the local ecological situation. Grobman (1970) gives the following example:

> According to the BSCS, animal specimens discussed should be those that are indigenous to the country, not those in an imported book. In requiring adaptation rather than permitting translation, the BSCS is trying to avoid the situation reported by a visitor to Hong Kong, where students in a biology class were following the laboratory directions in a British book for the dissection of an earthworm, as preparation for the British University examinations; but the students were dissecting local earthworms. The students' laboratory reports describing their dissections conformed with the information in the laboratory manual, even though the earthworms they were dissecting did not. (p. 136).

Local mores also affect the teaching of biology. Thus in India the dissection of animals in biology classes would cause problems; the discussion of evolution or of genetic differences among races does not.

It might be argued that course materials in some other disciplines such as mathematics or physics might be more "culture-free." However, experience in a number of countries has shown that American materials, even when their content is reasonably appropriate, will not be received as enthusiastically as materials that are produced by a well-planned local effort.

The Science Education Center at the University of the Philippines (UPSEC) was established as a result of one such local course development effort. Its initial task was to adapt the BSCS course materials developed in the United States to the needs of schools in the Philippines. It is unlikely that the pride in local achievement or the commitment of the government to the project would have been as great if a direct translation of the BSCS materials had been attempted. The original project funded by the Ford Foundation and UNICEF was so successful that the Philippine government provided sufficient funding in 1969 to establish UPSEC on a permanent basis so that it could continue to develop science and mathematics materials for schools in the Philippines.

Optimal results seem to be achieved when a curriculum development project in a less developed country utilizes the best programs already developed in other countries as resources to design new course materials that fit the local situation. However, it is essential that such materials then be subject to repeated cycles of revision based on the results of trial-teaching in the local schools. Experience has shown that the most effective way of creating such feedback loops is for the curriculum developers to involve themselves in the classroom trials of the experimental materials.

The African Primary Science Program is a good example of a project which functioned in this way. The project's basic purpose was to introduce modern methods and materials for teaching science into the primary schools of English-speaking tropical Africa. Its specific objectives were:

1. To develop a range of materials using the local environment and covering a wid diversity of science topics.

2. To assist with the establishment of a network of locally-manned and controlled science centers where continuing development might take place.

3. To encourage the formation of an African organization able to provide interested countries with assistance in the area of science education and to conduct various international education activities.

The APSP had a number of unique characteristics as a curriculum project. First, personnel in the various science centers established by the program adopted a truly experimental approach to the development of science units for primary schools. Although frequent use was made of ideas contained in materials previously developed in the U.S. and England (especially the Elementary Science Study and Nuffield Junior Science Teaching Project), the main emphasis of the APSP's work was not on the adaptation of materials developed for use in industrialized countries. Instead, an effort was made to develop learning activities that were modern with respect to content and approach but geared to the realities of the local African situation. Ideas for learning activities were selected that would be relatively easy to teach in simple village schools, using materials that could be found locally. Instructional units were not written in final form until the activities had been successfully taught to children in typical village primary school classrooms. Local primary school teachers were encouraged to participate in this trial-teaching process.

Second, the APSP focused on the development of the child, rather than structuring the program around the discipline of science. APSP science activities were designed to help children to develop cognitive and manipulative skills, as well as curiosity, persistence, self-reliance,

and a respect for scientific reasoning.

Third, the APSP project was unique in that it was a Pan-African program which involved science educators in fourteen different African countries. Experimental versions of materials developed by the APSP were trial-taught in several African countries simultaneously and final versions of the teacher's guides were usually prepared at international workshops that were held periodically in various participating countries.

An African-directed organization, the Science Education Program for Africa (SEPA), was founded to carry on the work of the APSP project. SEPA receives funds for its basic operating expenses from participating African governments, and obtains project funding from a variety of agencies, including both USAID and Unesco (Dyasi, 1978).

Teacher Education Efforts

The development of new course materials in science and mathematics has placed new demands upon the education of teachers. Although in the early years of the curriculum reform movement, some developers may have cherished hopes that their materials were so well structured as to be "teacher-proof," experience has shown that unless teachers are given adequate training in the use of new materials, very little happens when they are introduced into the classroom except the substitution of one textbook for another.

Because teachers tend to teach as they were taught, any significant change in the curriculum requires a teacher-training effort specifically directed toward the implementation of that change. Science and mathematics course improvement projects have generally incorporated one or more of the following types of innovations: (a) new scientific content, (b) new approaches to the teaching of science, and (c) new kinds of

instructional materials and apparatus.

The new courses have several types of new content that is unfamiliar to most teachers. New concepts are usually emphasized, as well as a more modern treatment of traditional topics. Many of the new "integrated science" courses have a breadth of coverage that extends well beyond the bounds of the discipline-centered academic backgrounds of most science teachers. There is also an emphasis in many of the new courses on societal concerns such as the degradation of the environment and the depletion of natural resources, value-laden areas which most science teachers are ill-prepared to discuss with their students.

The new approaches to teaching utilized in the new courses place even heavier demands on the education of teachers. The most recently developed courses emphasize that teaching should be geared to the cognitive development of the child. This requires a shift in the role of the teacher from the old authoritarian role of one who imparts knowledge to a new role as a facilitator of learning. The new role requires that teachers become adept at teaching children to observe, measure, and predict; to manipulate apparatus; and to construct and interpret charts and graphs. Many of the new courses also include some affective objectives which many teachers have not previously considered to be important.

Most of the new science courses incorporate an emphasis on "hands-on" learning through the use of a variety of instructional materials and apparatus. If new materials and apparatus are to be provided to teachers, it is important that they be taught how to assemble, use, adjust, and repair this apparatus so as to maximize its cost-effectiveness. In cases where teachers are expected to improvise apparatus from local

materials, it is especially important that teachers know how to construct and use such improvised apparatus.

The experience gained from teacher education efforts in the past--both in the United States and abroad--has indicated that too much emphasis has been placed on purely subject-matter training, despite the emphasis in most of the new programs on the adoption of new teaching approaches. This may reflect an assumption that if a teacher is taught the subject matter of a course, and is told to use discussion or inquiry methods, he will do so. However, evaluation studies have provided clear evidence that this approach is not usually effective (Grobman, 1970, p. 164).

If changes in teaching methods are required, then teacher-training programs must focus on the new methods. Perhaps the best strategy for providing this training is to actually give teachers an opportunity to work with the materials they will later be using in their classrooms.

Such activities were a basic feature of the summer inservice training institutes for secondary school science teachers sponsored by the Brazilian Foundation for Science Education Development (FUNBEC), which was founded by Isaias Raw. In these institutes, teachers performed and discussed some of the basic experiments in the new FUNBEC courses, observed classes being taught with the materials, and taught selected portions of the new materials either to demonstration classes or to other teachers participating in the program. More recently, FUNBEC has turned to the training of leaders to staff a national network of six centers for the inservice training of science teachers (CECI).

Curriculum reform projects often begin with an emphasis on inservice education as a means to secure rapid implementation of the program in existing classrooms. As time goes on, and the new program becomes

adopted as part of the regular curriculum of the schools, it becomes necessary to upgrade the pre-service education of new teachers. However, the reform of pre-service teacher education can prove to be one of the most thorny problems confronting curriculum innovators, since tutors in teacher-training colleges often view curriculum reforms as a challenge to their special areas of expertise.

One institution that has been especially effective in the improvement of pre-service teacher education is the Science Education Center at the University of the Philippines (UPSEC). As mentioned earlier, this center grew out of early efforts to adapt the BSCS materials for use in the Philippines. Although the initial emphasis of its activities was on curriculum development, it later began to focus on the improvement of science teacher education.

A scholarship program funded by UNICEF and the Philippine National Science Development Board brings forth teacher educators to the center each year. These science educators, who come from thirteen teacher education institutions located throughout the Philippines, are enrolled in an 18-month program designed to improve the subject area background of the participants, expose them to new developments in science education, train them in new teaching and evaluation techniques, and help them to develop new approaches to the education of teachers. Teacher educators who have completed this program take back to their teacher-training institutions the basic equipment needed to conduct pre-service training programs for teachers. Five of the thirteen teachers' colleges participating in this program have been designated as Regional Science Teaching Centers, and work closely with UPSEC in the dissemination of new curriculum materials (Garcia-Roque, 1974).

The Design and Production of Instructional Materials and Equipment

The findings of cognitive psychologists concerning the importance of concrete experiences in the development of abstract reasoning have supported the intuition of the early curriculum reformers who made "hands-on" activities a central feature of their new courses. Whereas in the past, schools may have attempted to economize by conducting many experiments as teacher demonstrations, today most educators realize the shortcomings of such an approach.

Problems associated with imported apparatus. Providing schools with an adequate supply of equipment and materials for the teaching of science and mathematics has posed a serious problem for most of the less developed countries. The disadvantages of importing educational supplies and apparatus from industrialized countries are well-known to anyone who has worked in the schools of a developing country. First, such imported items are extremely expensive, due both to shipping costs and to the relatively high cost of labor in industrialized countries. Aside from the expense to the purchaser, the importation of equipment also requires foreign exchange. Once a piece of apparatus has been obtained, often after a delay of many months, one still faces the difficulty of obtaining the expendable supplier necessary to operate the appartus over a period of several years. If a piece of apparatus breaks, there is a similar problem of obtaining spare parts and if factory repairs are required, shipping costs may be prohibitive.

In addition, there is undoubtedly an unhealthy psychological effect on teachers and students if items of basic educational equipment that could well be manufactured locally are always imported from the industrialized nations. If every time a class is called upon to do a scientific

experiment, they must work with apparatus imported from Europe or the United States, students are likely to get the idea that scientific endeavors are solely the province of the industrialized nations.

There is also a danger, especially at the elementary school level, that the "standard" science equipment imported from the major commercial suppliers may not be designed to fit the needs of the local curriculum. Earlier it was stressed that developing countries need to mount their own curriculum development efforts to produce textbooks and instructional materials that adapted to local needs and conditions. This course development process should also include the design of laboratory activities and the apparatus needed to perform these activities. A requirement to use the standard apparatus found in the catalogs of commercial equipment suppliers would compromise the effectiveness of the course development process considerably.

Many of the new science course development projects in the United States did design new types of apparatus for student investigations. This was done partly to reduce equipment costs so as to encourage the adoption of the new programs in school systems with limited budgets. The Physical Science Study Committee, for example, pioneered in the development of inexpensive but functional designs for student apparatus that could be constructed from wood, chipboard, and mass-produced hardware items such as doorbells and roller skate wheels. Such equipment was much less expensive to produce than the traditional designs which had been manufactured to close tolerances from machined brass and polished mahogany.

The Introductory Physical Science (IPS) project continued this approach in the development of a series of chemistry experiments for junior high schools that could be performed with the use of a simple

pegboard stand, to which broom clips could be bolted to mount test-tubes, alcohol lamps, and other pieces of apparatus. At the elementary school level, the Elementary Science Study used a similar approach to develop designs for simple equipment that could be constructed from inexpensive materials.

Although the new apparatus designs were originally developed primarily to reduce costs, the use of unsophisticated apparatus has resulted in some important pedagogical benefits as well. If students in a introductory science course are required to use complicated-looking pieces of apparatus, replete with knurled knobs and vernier scales, they are likely to be intimidated and may revert to a cookbook style of doing experiments. The use of simpler apparatus, constructed from easily recognizable materials, is more likely to encourage students to strike out on their own, experimenting with making impromptu adjustments to discover "What happens if...?" The confidence gained from such successful encounters is an important outcome of elementary and secondary school science education, although not something that is usually measured by achievement tests.

The use of simple apparatus manufactured from familiar materials is especially important in rural areas where there may be a tendency children to attribute magical causes to scientific phenomena. If such children are to develop a sense of "fate-control" and a capacity for making rational decisions concerning the adoption of improved health practices or agricultural technology, they need to begin working with simple concrete problem-solving materials early in elementary school, so as to develop a capacity for detecting cause and effect relationships.

Improvised science apparatus. Several international development assistance agencies have supported the development of publications to help teachers construct simple science apparatus from common materials that can be found locally. Probably the best known of these publications is the UNESCO Source Book for Science Teaching (1973), which describes the construction of hundreds of pieces of apparatus for teaching science, with emphasis on the primary and early secondary levels.

The science units developed by the African Primary Science Program include many suggestions for equipment that can be improvised by teachers from materials that might be obtained in a local market. Another source of ideas is the series of three books on improvised science equipment published by the University of Maryland Science Teaching Center (Melton, 1972). The three volumes in this series (on biology, chemistry, and physics) include a variety of designs for simple science equipment collected from projects throughout the world.

However, it is one thing for a science teacher to construct a few items of improvised apparatus in order to present a demonstration for his class; it is a task several orders of magnitude larger to construct enough apparatus to enable an entire class to perform science activities throughout the school year. It is unrealistic, particularly at the secondary school level, to expect that many science teachers will be able to find sufficient time or materials to perform such a task. Even the simplest kinds of materials cost some money and take time to gather and assemble.

Some countries have set up arrangements to supplement materials obtained locally with a limited selection of simple science apparatus obtained through UNICEF. The Papua New Guinea Primary Science Project

is a good example of such a project. UNICEF supplied this project with sixteen types of simple apparatus for children and about twenty additional kinds of materials for teacher demonstrations. The children's materials supplied included items such as alcohol burners, beakers, rubber tubing, magnets, magnifiers, and flashlight bulbs; materials for the teacher included test tubes, a thermometer, and chemicals. The remainder of the materials needed for the science program are common domestic items such as torch batteries, mirrors, razor blades, candles, and balloons that can be obtained locally.

With the assistance of UNESCO, UNICEF has now produced a guideli: of standard science teaching equipment such as that used in the Papua New Guinea project. The items on this list, called the EVE list, are stocked at the UNICEF warehouses in Copenhagen and supplied to projects in developing countries at a low cost made possible by bulk purchases (UNICEF, 1973).

The use of cottage industry. Another mechanism to increase the supply of science apparatus and materials in schools is the development of a local cottage industry to construct simple science apparatus. This has been done in several countries by the African Primary Science Program (now the Science Education Program for Africa) in order to provide teachers with kits of the simple science apparatus specified in the various APSP units. At the APSP centers in Tanzania and Uganda, unskilled primary school graduates were hired and trained to construct simple apparatus such as bead microscopes and kits of materials for the APSP units. These kits were then supplied to the teachers who attended in-service training institutes.

It has also been possible in some countries to work with pre-service teacher training institutions so as to provide the new graduates of these colleges with science kits. One way in which this can be done is to set up a workshop at the teacher-training college and provide student teachers with the tools, materials, and time to construct their own kits of apparatus during their residence at the college. An added benefit of such an arrangement is that teachers are equipped with the skills necessary to repair or replace their equipment when it gets broken. Obviously, such an arrangement is most suitable for the elementary school level, since the necessary apparatus can frequently be constructed from wood, using simple hand tools.

The use of plastics. The use of plastics for the local construction of apparatus is also feasible. In many developing countries, small plastics factories are in operation for the manufacture of domestic items such as basins and bottles. In Tanzania, it was possible to have such a factory design a mold to manufacture geometrical attribute shapes. A set of these shapes can be used in a variety of ways to teach classification skills to elementary school children.

A variety of plastic molding techniques have been used by recent science course development projects. In the United States, the Science Curriculum Improvement Study has demonstrated the practicality of using vacuum-forming techniques to manufacture simple science apparatus for elementary schools. Injection-formed plastic apparatus is used in the physical science courses developed by the Intermediate Science Curriculum Study. If suitable precision molds and dies can be obtained, there is no reason why local plastics industries cannot manufacture similar apparatus for use in the developing countries.

Large-scale equipment production center. A number of countries have set up large-scale national science equipment manufacturing operations. One of the earliest such efforts was the Science Equipment Workshop established at the Rangoon Arts and Science University with the help of Soren Hakansson, a UNESCO advisor, who has helped to set up many of the apparatus production schemes in South East Asia. The production unit in Burma began producing physics and chemistry equipment in 1965 for 450 state High Schools. By 1972, production had increased to a level of 40,000 U.S. dollars worth of equipment per year (Warren & Lowe, 1975, p. 20).

Attempts have been made to establish facilities to develop or produce school science equipment in many other countries, especially in South East Asia. In a few countries, such as Sri Lanka, the model established in Burma is used, where the production of science equipment occurs at the government facility itself. In other countries, particularly those with an established tradition of small-scale manufacturing, the government science equipment center develops equipment designs, produces and tests pilot models to ensure their suitability for use in the schools, and attempts to encourage private manufacturers to undertake the mass production of the perfected designs. This is the approach used in the project being undertaken by the National Council for Educational Research and Training (NCERT) in India to supply kits of science apparatus to the primary and secondary schools. At the primary level, the NCERT workshops produced prototype kits. UNICEF then supported the mass production of these kits by local industry. As of 1975, 20,000 NCERT primary science kits had been produced. However, this was a small fraction of the total need, since there are 500,000 primary schools in India.

Malaysia provides a very successful example of how the local production of school science apparatus can be managed. The Curriculum Development Center in Kuala Lumpur develops new prototype equipment designs, and helps local manufacturers with the development of new manufacturing techniques. It has been estimated that Malaysia now manufactures more than half of its secondary school science apparatus requirements.

The Center at Kuala Lumpur has been assisted in its work by the Regional Center for Education in Science and Mathematics (RECSAM) in Penang, Malaysia. RECSAM was established by the South East Asian Ministries of Education Organization (SEAMEO), and serves Thailand, Malaysia, the Philippines, Indonesia, Singapore, Laos, and Khmer. In addition to sponsoring conferences and teacher-training activities, personnel at the RECSAM center have developed some prototype designs for science apparatus.

In Thailand, the Institute for the Promotion of Teaching Science and Technology (IPST) was established in 1971 with UNDP funding to develop course materials and apparatus for secondary school biology, chemistry, and physics, as well as a course in integrated science for the lower secondary level. Production runs of as many as three hundred pieces of prototype apparatus were manufactured at this center in order to supply equipment to the trial schools and teacher-training colleges. The large-scale production of school science equipment for schools in Thailand is to be undertaken by the Kuru Sabha Company, which is a commercial enterprise of the Teachers Association of Thailand. IPST personnel will assist with the development of large-scale production designs (Sapianchai & Aylward, 1977).

The educational system in the Philippines has not found a satisfactory solution to the problem of supplying science apparatus and supplies to the schools, particularly at the primary and intermediate levels. As described earlier, the University of the Philippines Science Education Center (UPSEC) has been very active in curriculum development and in assisting the teacher-training colleges with the dissemination of the materials produced at the Center. However, it was assumed that the manufacture of materials and apparatus could be left to local industry. Unfortunately, private manufacturers have not shown much interest in the educational market, perhaps because there is very little certainty that schools will be provided with sufficient funds to purchase science equipment, even if it is produced economically. A UNESCO-UNDP study was commissioned in 1972 to examine the problems of supplying science equipment to Philippine schools. It recommended that a pilot production unit be established to demonstrate to local industry the feasibility of local production, but no action has yet been taken on this recommendation.

In Latin America, the most successful and largest-scale effort for the local production of science apparatus has been at the Brazilian Foundation for Science Education Development (FUNBEC). Originally known as IBECC, FUNBEC was established by Isaias Raw in 1952 to assemble science kits for high school students. These kits were marketed directly to students through commercial channels, and students who purchased the kits also received a monthly science magazine. The science kits were so well received that in 1954 the Sao Paulo State educational authorities and the Brazilian Federal Ministry of Education requested that IBECC begin supplying science equipment to the schools. By 1960, IBECC had supplied

science equipment to over 2000 Brazilian secondary schools.

Although IBECC eventually expanded its role to include the development of a wide variety of science currriculum materials for the schools, the emphasis on providing an alternative mechanism for teaching some students directly through small science kits has remained. Isaias Raw described his rationale for this approach in a report written in 1960:

> To achieve quick results and not to abandon the present generation of students completely, we decided to work directly with them. This approach has the advantage of avoiding all the school problems. The method employed is again laboratory experiments. Students are supplied, at cost price, with small laboratory kits.
>
> These kits are not used as toys but to conduct experiments and help good students to develop a scientific mind; to enable them to conduct experiments and reach conclusions by themselves, the purchaser of the kit is supplied with a free monthly journal that contains experiments (Maybury, 1975, p. 27).

In recent years, FUNBEC has been responsible for the design of a series of fifty pocket-book size science kits which are marketed on newstands throughout Brazil. Each kit contains the biography of a great scientist as well as an experiment illustrating his work, which can be performed with the help of the simple materials and instruction book provided in the kit. In addition, there are three volumes of a text which can be obtained separately. The entire set of materials is imaginative and designed to appeal to young scientists on its own merits.

This FUNBEC commercial venture is one of the few institution-based equipment production units that has actually shown a profit. In both

the less developed nations and the industrialized countries the viability of both public and private production units whose sole purpose is to manufacture equipment and materials for use by schools is questionable unless careful advance planning is done. Large capital investments in sophisticated manufacturing equipment cannot be justified unless the estimated production volume is large enough to pay for the tooling costs. The estimated production volume unfortunately cannot be based on educational needs; instead it must be based on a pragmatic assessment of the school system's wants, which must in turn be based upon the funds that can be made available by the government.

However, given sound planning, a publicly-owned manufacturing unit theoretically can produce school science equipment and materials at a lower cost to the government than would be possible relying totally on the private sector. In most countries, privately-manufactured educational materials and equipment are relatively expensive, not only because of the need for a reasonable profit margin but also because considerable capital must be tied up in shelf inventories of stocked items, due to the highly variable and difficult to predict school market demands. Publicly-owned production units whose sole purpose is to manufacture items for use by government schools should be able to scale their production precisely to a predetermined demand, and thus produce apparatus at a lower cost to the government.

In many countries, total self-sufficiency in the manufacture of science apparatus may not be cost-effective. However, past experience indicates that considerable savings can be accomplished even in small countries by setting up local instructional materials processing centers that can use local labor to assemble apparatus from some local materials

and some imported parts. Usually the necessary imported parts can be purchased in bulk from the original manufacturers much more cheaply than the prices charged by the traditional distributors of school laboratory equipment. Items commonly used for purposes other than education, such as automobile battery chargers, hospital glassware, and many hardware items can be obtained more cheaply than items designed solely for use in schools. Such modifications as are necessary can often be performed efficiently by local production units with a modest amount of power wood-working and sheet-metal forming tools.

The Use of Educational Technology

Distant teaching systems. For a number of years, educators have been looking for ways by which modern technology might be used either to improve the quality of education in less developed countries or to increase its cost effectiveness. One of the approaches that has received considerable publicity has been the use of public media such as television and radio for "teaching at a distance."

The educational potential of television broadcasting has been demonstrated on a large scale in the United States by the programs developed by the Children's Television Workshop and by the Open University courses developed in England. However, the expenses involved in the development of quality television programming, as well as the costs of transmitting and receiving equipment, make television impractical for use as an educational medium in most of the less developed countries.

The use of radio for educational programming is considerably less expensive. Radio receivers are comparatively inexpensive and can be operated on batteries in rural areas where mains electricity is unavailable.

The Stanford Radio Mathematics Project in Nicaragua has demonstrated the feasibility of using radio programming to improve the computational skills of children in the primary grades. Although the development of the series of daily radio broadcasts in Nicaragua was quite costly, evaluation of the project revealed that student repetition rates had been sufficiently reduced to offset the program development costs (Searle, Friend,& Suppes, 1976).

The Radio Mathematics lessons were designed to encourage the active participation of students, using simple materials such as seeds, bottle tops, and stones. During the broadcasts, students were required to respond at an average rate of five responses per minute; these responses could be oral, written, or involve physical movement. As a result, program evaluators found that students participating in the radio lessons were more actively involved in the learning process than those in traditional Nicaraguan classrooms (Suppes, Searle, & Friend, 1978).

However, distant teaching does have some inherent limitations and is undoubtedly more suited to the development of simple skills than to the teaching of more complex conceptual material. The experience of the Open University in England suggests that, to be fully effective, one-way media presentations need to be supplemented with opportunities for face-to-face teaching. It is also important to recognize the difficulty of tailoring distant teaching programs to the culture and world view of the listening audience. The extensive feedback system that is necessary to perform this task can make the development of programs quite expensive.

Other educational media. In addition to educational broadcasting, modern technology has provided teachers with a large variety of devices

which have a potential for enhancing classroom instruction. "Multi-media instruction" covers a wide variety of instructional techniques, including the use of video-taped television programs, computer-based instruction, motion pictures, audio tape recordings, overhead projection transparencies, and 35 mm filmstrips and slides.

All of these techniques can be educationally effective, but their use in a given situation must be carefully weighed in terms of local conditions and other competing needs. Clearly, some educational technologies are more appropriate than others for use in the less developed countries.

However, because sophisticated educational technology is glamourous, it is often purchased by schools for the sake of prestige rather than utility. Warren and Lowe describe a case of a Vietnamese educational official with such an orientation:

> In a recent conference, the Vietnamese delegate officially reported his country's difficulties in terms such as "How can we get an overhead projector easily?" "How can we buy a video recorder without tax?" Meanwhile, the morning's newspaper (which the conference delegates had just read) carried pathetic pictures of children taking home-made desks along to sit on the beach near Quang Tri. Formal reports at international conferences often do not show the truth, and this in no way helps donors to hit the right level of international aid. The USAID program has supplied Vietnam with one hundred movie projectors; the Overseas Technical Agency of Japan has given video-tape recorders to set up an audio-visual center. Yet, in most Vietnamese schools there is no electricity; only a few of the largest schools have a laboratory; and there are no repair facilities except in the central workshop in Saigon (Warren & Lowe, 1975, p.31).

In general, the sophisticated hardware that is available for use in schools is not matched by educational software of comparable quality. Albert Baez, former Director of UNESCO's Division of Science Teaching, recommends that ministries of education in less developed countries concentrate on the development of software which can be used with relatively inexpensive equipment, such as 35 mm slide-tape programs. Such software is not difficult to produce with modest resources and can provide considerable visual enrichment.(Baez, 1976, p. 177).

In 1972, UNESCO held a meeting on new trends in the utilization of educational technology for science education in Montevideo, Uruguay. At this meeting, Isaias Raw, director of the FUNBEC center in Brazil, expressed a concern about the possible misuse of educational technology and cautioned the less developed countries not to place too high a priority on the acquisition of sophisticated equipment:

> In analyzing the use of educational technology in science education, a distinction is made between education and passive aquisition of information. The role sought for educational technology in in science education is that of providing active learning and individualized instruction, so as to cope with different learning styles, learning rates, and varieties of interest... ... This is a goal barely touched upon by the major stream of educational technology which is often conceived merely as a large-scale replacement of the lecture.
>
> As most schools in the less developed world are devoid of even the simplest slide projectors, the priority there should be, not for the teacher-aiding tools, but for low-cost laboratory equipment and other materials for student use. The less wealthy countries could

put more efforts in designing sets of multi-media units combining printed matter, short films, slides, and low-cost laboratory kits (Baez, 1976, p. 163).

IV. Programming Recommendations for the Institute for Scientific and Technological Cooperation

The Need for ISTC Programming in the Area of Science and Mathematics Education

A recent paper prepared by the Committee on the Teaching of Science of the International Council of Scientific Unions (ICSU) stresses the need to include mechanisms to improve the effectiveness and quality of science and mathematics education in the less developed countries as a part of any plans to utilize science and technology for development. Although prepared for the United Nations Conference on Science and Technology for Development (UNCSTD), this report provides a clear rationale supporting the inclusion of programs to improve science and mathematics education as one component of ISTC's activities:

> It is our opinion that the healthy growth of science and technology in any country depends critically on the availability of technically and scientifically trained manpower and that it is the responsibility of the indigenous educational system to provide such manpower.
>
> Furthermore we would maintain that the successful exploitation and assimilation of scientific and technical developments can only proceed with the support of an interested and informed public. The responsibility for fostering this interest, and for ensuring that the public is properly informed rests clearly with the educational system of the country concerned. Any policy that fails to recognize the importance of these two factors can, at best, produce only short term improvements; at worst the country concerned could exper-

ience serious failures in technological development.

> Long term sustained growth can be assured only if the money invested in science and technology is matched by the provision of funds for complementary educational programmes directed both to the preparation of scientists and technologists and to the improvement in scientific literacy of the population as a whole (ICSU, 1978, p. 5).

In particular, the ICSU report indicates that the following kinds of efforts are needed:

> In order to promote self-reliance and understanding there needs to be a massive reappraisal of the content of existing courses, at school and at the university, if they are to reflect the needs of the developing countries.
>
> It is also accepted that there is a need to change attitudes and this requires the development of new teaching techniques. For this there must be substantial assistance for the provision and support of teacher-training and teacher re-training. . . .
>
> There is also a considerable need for the development and production of low-cost locally-produced equipment and teaching aids. A number of developing countries are working on this, . . . but further support is necessary (ICSU, 1978, p. 10).

Many American scientists and educators have been involved in the past in efforts to improve science and mathematics education in the less developed countries. However, much of this assistance has been ad hoc and dependent upon chance encounters between individuals. The lack of long-term coordinated efforts to provide assistance and maintain contact with science education centers overseas has caused personnel in education projects initiated with U.S. assistance to become isolated from new developments

in science and mathematics education and from colleagues in the United States who might be able to assist them. The recommendations in the following pages will suggest ways by which this situation might be changed.

Science and Mathematics Curriculum Development

Only a few countries in the world possess sufficient resources -- including both money and the necessary trained scientific manpower -- to create totally new curriculum materials for all educational levels. For this reason, many developing countries have taken the shortcut of adapting course materials developed elsewhere. This process is most successful when the most suitable elements are selected from a variety of project materials, so as to synthesize a new course that best fits local needs and conditions (Blum, 1979).

The United States is in a position to be of considerable assistance in these efforts, since it occupies a position of leadership in science and mathematics curriculum development. ISTC efforts in this area should focus primarily on helping science teaching centers in the less developed countries with the identification, adaptation, and synthesis of course materials so as to meet local needs and on improving local capacities for science and mathematics curriculum development.

However, it will be difficult for the ISTC to be effective in improving science and mathematics education in less developed countries if its mandate requires it to be strictly problem-centered, since education is a specifically national concern and solutions to educational problems must be designed to fit local institutions and conditions. Although there are some regional organizations, such as the Science Education Program for Africa (SEPA) and the Regional Center for Education in Science and Mathematics in Malaysia (RECSAM), that have achieved a

degree of cooperation between groups of countries, in many other instances this type of regional cooperation will not be possible. If ISTC is to be maximally effective, it will need to undertake pilot program efforts in specific countries. It should then be possible to share the benefits of such pilot porjects with educators in other countries through the development of institutional networks.

In many less developed countries, science and mathematics education specialists experience a feeling of isolation due to a lack of colleagues with whom they can communicate on a professional level. This situation has worsened in recent years due to cutbacks in funding for international curriculum development activities by the major foundations and technical assistance agencies.

A related problem is the difficulty which many educators in small countries experience in keeping abreast with recent educational developments in the West, since professional publications are expensive and difficult to obtain in many countries. ISTC support for the establishment of a communication network and international resource center for science and mathematics education would help to alleviate these problems.

Recommendation 1. Accept proposals from curriculum development centers in the less developed countries to supply U.S. scientists and educators to work collaboratively with local personnel on the development and implementation of new science and mathematics course materials. The objective of such efforts would be to share new developments in science and mathematics education and to improve local curriculum development capabilities.

Recommendation 2. Support the establishment of science and mathematics education centers at universities in the United States with a focus on the training of LDC educators from a particular geographical region. These

centers could be modeled on the program established at the University of Wisconsin by Milton Pella to train science educators from the Arab countries of the Middle East. Consideration should be given to the establishment of training grants and postdoctoral fellowships as well as academic degree programs.

Recommendation 3. Establish internship programs at curriculum development centers in the United States such as the Lawrence Hall of Science and the Biological Sciences Curriculum Study (BSCS). Such programs could operate independently as one-year internships or be set up as summer programs to complement the university training of students from less developed countries in U.S. institutions.

Recommendation 4. Sponsor internship programs for LDC science and mathematics educators at established national curriculum development centers in the less developed countries or in conjunction with regional institutions such as SEPA and RECSAM. Such internships would facilitate the development of linkages to encourage cooperation between developing countries in the area of science and mathematics education.

Recommendation 5. Encourage the development of networking arrangements that will encourage scientists and educators from the less developed countries who are engaged in science and mathematics curriculum development work to share experiences and materials, as well as plan new approaches. This function could best be achieved by a small ISTC education staff which could identify groups of people with common interests, organize meetings to discuss common problems, and present progress reports on new projects. Some of these meetings might be held at science education centers in the developing countries, so as to enable participants to visit successful projects in the host country.

Recommendation 6. Establish a science and mathematics education resource center that would help keep educators in the less developed countries up to date on recent developments and research in science and mathematics education. The staff of such a center could respond to inquiries from developing countries with a brief analysis of projects currently underway, plus suggestions regarding key individuals and institutions that might be able to provide additional assistance. Although such a center could be located at a university, some important advantages might result if the center were to be located at the ISTC office. This would enable ISTC personnel to be at the center of the proposed communication network, rather than at its periphery. By mazimizing feedback from the field, such a center would help to ensure that ISTC programming would remain realistic and relevant to actual needs in the less developed countries.

Teacher Education

Although the large-scale implementation of programs in the less developed countries must ultimately be carried out by local personnel, there is a need to learn more about how science and mathematics education programs that have been found to be effective on a trial basis with small groups of teachers and students can be implemented effectively by large numbers of teachers. Studies of effective implementation strategies and research into the processes involved are both needed.

The development of new approaches to the pre-service and in-service education of science and mathematics teachers is essential if course improvement programs are to result in substantive changes in the way students are taught. In order to plan such new approaches to teacher training, it will be important to collect better baseline data about the

current state of science and mathematics teaching in the countries concerned.

Recommendation 7. Support the development and documentation of effective models for the improvement of pre-service and in-service teacher education in science and mathematics.

Recommendation 8. Support the development of new materials for the education of science and mathematics teachers which might be used to introduce teachers to new approaches to science and mathematics instruction. Some excellent teacher education materials have already been developed by several projects in the United States, such as the ISCS Individualized Teacher Preparation Program modules (ISCS, 1975) and the Science Teaching and the Development of Reasoning units developed at the Lawrence Hall of Science (Karplus et al, 1977).

Recommendation 9. Initiate studies to document current practices and problems in pre-university science and mathematics education in the less-developed countries in a given geographical region. Such studies could be modeled on the Case Studies in Science Education completed by Stake and Easley (1978) to assess the situation in American schools for the National Science Foundation. Such studies could provide information on the kind of science and mathematics education that is actually occurring in the elementary and secondary schools as well as the teacher training colleges of a given region, and would provide a basis for designing future teacher-training and course development programs. Hubert Dyasi of the Science Education Program for Africa has already made a proposal to ISTC to carry out such a study for Sub-Saharan Africa.

The Production of Low-cost Apparatus and Teaching Materials

The Commonwealth Secretariat has sponsored three conferences in recent years to discuss alternative approaches to the local design and production of school science equipment. Three regional seminars have been held in Nassau, Bahamas in 1976; Dar es Salaam, Tanzania in 1977; and Papua New Guinea in 1979. The reports of the first two conferences have been published by the Commonwealth Secretariat (1977a, 1977b), as well as a report which describes in detail four existing materials production centers which are now functioning in the less developed countries (Apea & Lowe, 1979).

These reports indicate that local science equipment production centers can be a viable and potentially useful element in a country's development effort. Because the United States has considerable expertise in the design and production of low-cost science apparatus, this is an appropriate area to provide collaborative assistance to the less developed countries through the ISTC.

Recommendation 10. Provide funding for studies to demonstrate the feasibility of establishing centers for the local manufacture of science instructional materials and apparatus in countries where such institutions do not presently exist. Such feasibility studies should include small-scale efforts based at teacher-training colleges and technical schools as well as large-scale manufacturing operations that serve an entire country.

Recommendation 11. Establish, through Volunteers in Technical Assistance (VITA) or a similar organization, a network of volunteer technical consultants who can communicate directly with personnel in overseas science equipment production centers to provide assistance with the

design of low-cost apparatus and manufacturing techniques. VITA is already operating such a volunteer consultant service in the area of appropriate technology.

Recommendation 12. Provide short-term consultants from the United States to work collaboratively with personnel at existing centers for the local production of science equipment in the less developed countries to perfect apparatus designs and manufacturing techniques.

Educational Technology and Out-of-School Learning

One focus of ISTC programming in the area of educational technology should be to provide support for the demonstration of cost-effective uses of distant learning systems, with an emphasis on the use of radio and including both in-school and out-of-school applications. In addition, support is needed for the development of local capacities in the less developed countries for the production of quality software for low-cost media techniques, such as tape-slide presentations or filmstrips.

ISTC could also help to alleviate the paucity of children's books and magazines about science and technology that are available to school children in the less developed countries. Most children have virtually no access to children's literature other than textbooks. A recent World Bank paper on education in India describes a study of a group of school teacher applicants: of the group questioned only 5% could think of a children's magazine and none could name a publisher of children's literature. (Heyneman, 1978, p. 14). ISTC could help to remedy this situation by supporting the development of a series of children's books or a magazine for young people focused on topics related to science and technology. Such publications could include information on applications of science and technology that are approp-

riate to the local situation, descriptions of the work of local scientists and technologists, and fictional stories about young people who are able to solve practical problems through the use of science and technology.

Recommendation 13. Fund pilot projects to encourage governments in the less developed countries to experiment with distant learning approaches such as the Stanford Radio Mathematics program, and provide collaborative assistance to help develop effective program sequences. Consideration should be given to the development of programs for use out of school as well as in school, and to the development of informative programs about science and technology as well as mathematics.

Recommendation 14. Provide support for programs to improve local capacities to develop quality software for use with low-cost media techniques, such as tape-slide or filmstrips. Topics which might receive special emphasis include descriptions of local applications of science and technology, scientific explanations of traditional technologies, and biographies of local scientists and technologists.

Recommendation 15. Support the development of a series of children's books or a magazine for young people in the less developed countries with an emphasis on science and technology. Such publications should be written by local scientists and educators, and could include explanations of scientific phenomena and local applications of technology as well as stories about children and adults who are acting in problem-solving roles. Several small books of this type have already been published as a part of the Science Library Series of the African Primary Science Program. The many "how to do it" booklets published in the United States for 4-H

clubs would provide a good model on which to base publications for secondary school students.

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