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Science for All

To create a scientifically literate populace, curriculum developers must downplay the conceptual structures understood by the scientific elite and instead emphasize exciting examples and everyday applications.

Photograph by Jim King

Although science curriculums introduced during the 1960s and '70s have solved the problem of an inadequate supply of scientific personnel, the price of this achievement in science education has been that the great majority of students have learned that they are unable to do science, that science is not for them.

After a decade of stagnation, science education in many countries is seeing renewed interest and nationally supported curriculum efforts.

In 1983 new funds in the U.S. initiated a number of projects. In Britain, the first major project since the '60s, the Secondary Science Curriculum Review, was established in 1982. Even earlier, New Zealand set up a Learning in Science Project in 1979 and, in 1982, a corresponding elementary school project. This new activity extends beyond developed or industrialized countries. In 1984 the Asia region of UNESCO, which ranges from Iran to Japan, endorsed a science education program as one its few priorities for the rest of the '80s.

In both rhetoric and rationale, these programs share in common a strong emphasis on Science for All. This slogan is a compelling and attractive one in societies where applied science and technology are evident in new products and new forms of communications. New jobs emerge and old, familiar ones disappear. There is a cry for new skills and expertise and a chronic toll of unemployed persons who lack technical skills.

The Science for All slogan has a democratic ring about it that implies there's something in it for everyone. It also acknowledges that science education in the past has *not* been science for all, that large numbers of persons have indeed been failed or passed over by the science curriculum. However, it should not be interpreted as a new educational intention or goal. The early 1960s are too recent and too well documented to be forgotten so easily. There was much in the writing and hopes of that massive wave of science curriculum endeavor around the world that spoke, in the language of those years, of science education that was to enrich the minds of all students. Although the activity of that decade initially focused on education in the more specialized disciplinary sciences of chemistry, physics, and biology, many projects then and in the early '70s aimed at mass education in elementary and junior high schools.

Simultaneously, this wave of curriculum development had affected countries all over the world, and the activity and exchange of ideas and materials for science education was quite unprecedented in any other field of the curriculum.

Historians of curriculum can take us further back to the 1860s in Great Britain and to the 1880s in the U.S. when a very promising approach to a science education for all was quite deliberately and ruthlessly obliterated because of the threat it held for a number of sectors of society. If we are to achieve anything in the present move for Science for All, we must see what we can learn from these earlier failures and from the ways in which they, in fact, succeeded in providing an education in science, not for all, but for a few.

Society's Demands on Functions of the Curriculum

Schools are established by society to fulfill a number of educational functions. The curriculum, in its parts and in its totality, is the instrument to serve these functions as well as the field where competing societal demands are resolved (see fig. 1).

The sciences, particularly the physical sciences in many societies, are gateway subjects that filter through the relatively few students who are allowed to move into professions of status, social experience, and economic security. Because of the social power associated with these positions, we can call this function a *political* function of schooling.

Again, a limited but definite number of persons with scientific skills and expertise are needed in any society to maintain and expand a variety of aspects of its economy. This limited population performs an *economic* function.

Scientists, particularly in research institutions and universities, are now a powerful faction with a major interest in maintaining their subject as an elite and important field. They are keenly interested in having the schools begin the process of reproduction of the sciences as those in higher education define them. This is the function of *subject maintenance*.

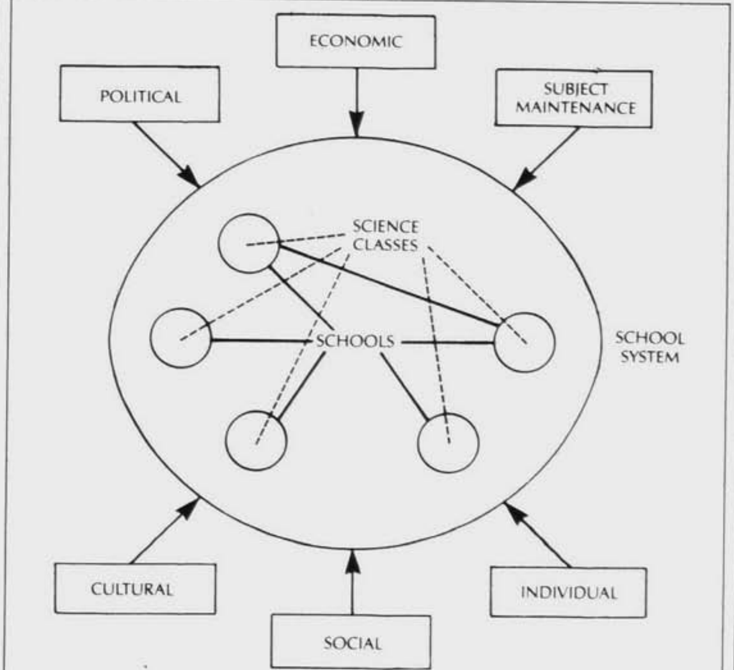

Fig. 1. Competing societal demands on schooling and science education

In addition, there are clearly a number of ways in which all *cultures* and *social* life are now influenced by knowledge from the sciences and its application. Human inventions in the sciences offer much potential for fulfilling the function of *individual* growth and satisfaction.

The first three of these social demands will be met, provided that only a relatively small number of students are successful in learning the sciences at school. Indeed, if a large number were successful, these social needs would be threatened by oversupply. Oversupply is an undesirable situation that has existed in many countries since the 1970s, when high school graduates' demand for places in higher education succeeded their availability and when persons with specialized training in science were unable to find appropriate employment.

The other three functions, on the other hand, are ones that relate to the whole population and will be met only if the majority of students successfully master the science curriculum.

Hence, these two demands are not simply competing but, in fact, are conflicting. Unless this is recognized and allowed for in the curriculum design for science education and in its implementation, there is no doubt one demand will win at the expense of the other. Indeed, there seems little doubt which will win since one has the backing of national imperatives like the economy and spheres of political influence, and the other, in comparison, may be seen as an essentially indulgent desire of the masses to improve their quality of life rather than fulfill specific, urgent needs.

Science Education for the Elite Few

Let me now turn to an analysis of the science curriculum movement of the 1960s-70s, and hence of much of our present science curriculums, to identify some elements that were quite contrary to our Science for All slogan and in the interests of educating an elite few in science.

1. The first curriculums to be redesigned in the U.S., Great Britain, Australia, Thailand, and Canada were those for the upper levels of secondary school where disciplinary sciences were taught, where only some of the school cohort studied them, and where they clearly existed as a prelude to further possible study in science.

2. This curriculum reform was very much in the hands or patronage of well-meaning academic and research-oriented disciplinary scientists, such as Pimentel at Berkeley for CHEM study and Nyholm at University College for Nuffield Chemistry, and similarly distinguished figures in physics and biology. To consider the nature of the reform these project teams brought about, it is important to have a measure of what actually resulted in classrooms, rather than what the rhetoric said was *supposed* to happen.

Descriptions of these courses and their guiding papers emphasize the structure of the knowledge of these sciences and the role of laboratory or empirical studies in its development. The courses were also designed with the very clear intention that both these features of natural science should be very explicit in the teaching and learning of science.

As a result, the direct uptake of these new courses and materials in Great Britain and the U.S. was not nearly as widespread among local school systems as was hoped. Furthermore, in practice in these countries and in many others where evaluative reports are available, there has been a selective emphasis on parts of these courses to the detriment of the new curriculum's intentions as a whole. The role of the laboratory, as part of the nature of science or as means of learning factual and conceptual knowledge, has been a major area of neglect. Most teachers and most examination systems seem also to have been unable to adopt the grand structural views of these science curriculums. Instead, they have turned them into conceptual statements, rules, and formulas to be learned without an adequate balance of the facts or realities of the natural phenomena to which they relate.

3. The teaching approach to this now heavily conceptual knowledge has too often followed a logical sequence determined by the significance of the knowledge in the discipline, and not by considerations of how it could be best learned. A concept is introduced, defined, quantified, refined, and then applied to more differentiated examples of the original concepts, and so on. This sequence of teaching is shown in Figure 2, in which each step is essential for the next but makes no sense of itself without a grasp of the steps that come earlier.

Such a teaching sequence turns out to be well suited to the tasks of sieving and sorting science students into an

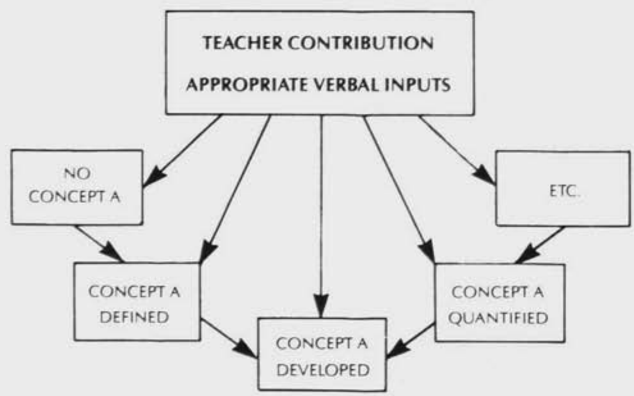

Fig. 2. The teaching/learning sequence for conceptual knowledge in many science curriculums

elite few, who become regarded as successful, and a majority, who are seen as failures and who reject science as being full of abstractions having little to do with phenomena in which they may indeed have an interest.

4. Science curriculums for the junior high and elementary levels were designed in a derivative way from this new thinking about the nature of science and its content for learning at the high school level.

Thus a number of projects around the world emphasized (a) the learning of science concepts at even very young ages (i.e., Concepts in Science, the Science Curriculum Improvement Study), and (b) the learning of *processes* of science—intellectual operations that scientists certainly use in their work but which in real life are never disembodied from the content of actual scientific phenomena in the way they were by these student projects. Numerous projects—ESS and AAAS Science (a process approach in the U.S.) and their derivatives around the world, Nuffield Primary Science and its derivatives, Science 5–13 Britain, and many other international projects—sought to provide meaningful learning for all through a curriculum that was based on these intellectual processes, which were then largely ignored by secondary school science teachers, who did not see them as useful tools for transmitting large amounts of factual and conceptual knowledge. They were also quite misunderstood by parents and elementary school teachers, who generally perceived science to be a body of scientific information they had failed to master during their own education.

Consequences of the 1960s and '70s Curriculums

The inadequacy of the earlier attempts to find a meaningful science for *all* levels of students is highlighted by comparing them with the situation in mathematics.

In mathematics, there is universal agreement that facility and understanding of elementary number operations are appropriate and highly desirable goals of the elementary school curriculum. Secondary school teachers want their students to have these facilities. They enhance the students' ability to learn not only the mathematics that secondary teachers want to teach, but also the learning of other subjects in the high school years. Furthermore, secondary teachers are not trained for, nor do they want to teach, these elementary operations. Parents recognize these number operations as familiar and important for their children, both now and in the future. Society and employers add their endorsements to this sort of elementary school mathematics, perhaps more than they should in these days of ready accessibility to other forms of calculation.

No such external recognition and support systems existed for the science curriculums that were introduced in the 1960s and '70s. Hence, those curriculums can be faulted for:

- encouraging the rote recall of a large number of facts, concepts, and algorithms that are not obviously socially useful;
- providing too little familiarity with many of the concepts to enable their scientific usefulness to be experienced;
- including concepts that scientists have defined at high levels of abstraction that are inadequately acknowledged in the school context and hence prevent appropriate explanation of their consequential limitations in real situations;
- involving an essentially abstract system of scientific knowledge, using examples of objects and events to illustrate this system, rather than those aspects of the science of actual phenomena and applications that facilitate some use or control of them;
- using life experiences and social applications only as examples or motivation rather than as the essence of the science learning;
- regarding practical scientific activity (if it is substantial at all) as a way to enhance conceptual learning rather than as a resource for learning essential skills; and
- giving high priority, even in biology, to the quantitative aspects of the sciences.

These curriculums are quite successful in meeting the societal needs I have associated with elite science. In country after country where reformed curriculums have been implemented since the 1960s, the problem of an inadequate supply of scientific and technical person-power has been solved. This is true in developing countries as well as in more industrialized and developing ones. A number of fields are oversupplied.

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The main price of this achievement in science education has, however, not been just neutral for the great majority of students who are not, in the end, involved in this elite group. It has been that the majority of students have learned that they are unable to learn science—that science is not for them.

There are other prices also, such as the degree to which the elite have to concentrate their later school years on the study of mathematics and the sciences to the exclusion of a broader curriculum. I would contend also that the elite, despite their concentrated learning of science, are also deprived of many aspects of learning science that have been excluded from their school science courses.

The Science Curriculum of the Future

This sort of analysis of the curriculum movement of the '60s and early '70s and hence of the present state of science in our schools can be used to begin to define characteristics that may be essential if science education is to be effective as Science for All and other characteristics that are at least worth trying.

First, elite or traditional science education must be confined to and contained within an upper level of schooling. It needs to be identified for what it is: a form of vocational preparation. Containment is not achieved by offering alternatives at the levels of schooling where Science for All is to be achieved. It is no good having a proper science for the few and a science for the rest.

Second, science must be reexamined and recognized as a variegated source of human knowledge and endeavor. A wider range of appropriate aspects of science needs to be selected for converting into the pedagogicial forms of a science curriculum that will have a chance of contributing to effective learning for the great majority of students. This is an epistémological task of a major order. It is, I suspect, a very radical undertaking that is quite beyond the science professionals to whom we have traditionally entrusted it. It is almost impossible to step aside from the intense socialization into science that any of us who are science professionals have experienced. Our ensnarement into science and scientific ways of thinking about the world is too great. For one thing, we have been specialized into only one or two of science's many forms. In addition, our success has transformed us into persons who think about the world and natural phenomena in ways that are quite different from the child at school or the nonscientific adult who may or may not be very successful in our highly technological society.

In order to try to think afresh about chemistry, the area in which I was socialized, I have made a three-dimensional model of the rich corpus of chemistry.

The facets of the model are all aspects of chemistry that chemists recognize as clearly within the confines of their subject. I can walk around it, stand back from it, and look at it. I can even cut through it and look inside. I can see it is about products and raw materials, rich colors and material structures, and involving people at many levels and over time. It affects jobs and careers and materials that clothe and shelter and feed and heal. It involves ideas and concepts and numbers and symbols.

What have we made of this rich complexion of chemistry for schooling? By and large we have reduced chemistry to one of its least exciting two-dimensional transects. School chemistry, apart from occasional visits to the laboratory, is the conceptual transect of this pulsating human adventure with colorful material substances. It is presented black and white on two-dimensional pages of textbooks or on chalkboards. Its learning is checked by students' two-dimensional responses to questions that are presented on two-dimensional test papers.

I have argued that present science curriculums are really an induction into science. The ones that might provide Science for All must involve much more learning about and from science.

These curriculum processes are quite fundamentally different. For instance, in the first we use teachers who have themselves been inducted into an acquaintance with some of the basic conceptual knowledge of an area of science to repeat the first steps of this process with their students. Since the teachers usually have little experience of the exciting practical applications of their knowledge or of the process of trying to extend the knowledge of a science, the induction they offer into the corpus of science is through the same abstract route they followed as part of a former elite who could tolerate it and cope with its learning. Few of their students are interested enough to follow.

In the alternative that I envisage for Science for All, students would stay firmly rooted outside the corpus in their society with its myriad examples of technology and its possibilities for science education. Science teachers, as persons with some familiarity and confidence with the corpus of science, will need to be helped to be not inductors but couriers between the rich corpus and their students in society. As students move through school, their experiences in society (school, home, community) will change, and they will encounter new situations to which science can contribute. Their teachers should dip into the relevant parts of the corpus and, from it, bring to their classrooms the science education that will enable their students to understand their world better and to believe increasingly that science and technology are great human inventions in which they can participate for their own and society's well-being.

Third, some clear criteria must be established for selecting the science that is to be the learning of worth. These also will need to be defined from outside rather than inside and then be ruthlessly applied so that the pressure from the traditional views of conceptual, scientific knowledge can be resisted.

Such criteria should include, for example, (1) aspects of science that students will very likely use in a relatively short time in their daily lives outside of school; and (2) aspects of natural phenomena that exemplify easily and well to the students the excitement, novelty, and power of scientific knowledge and explanation.

At a recent international curriculum workshop in Cyprus these two criteria were used to spell out a skeletal content for a quite new sort of science curriculum. They were found to be logically applicable in a range of broad topic areas such as senses and measurement; the human body; health, nutrition, and sanitation; food; ecology; resources; population; pollution; and use of energy.

In like manner we shall need to explore in the curriculum of Science for All what sorts of pedagogy are appropriate for the sorts of learning these much more variegated aspects of science require. Again we must start from outside science for these pedagogies and consider much more the learners themselves and the constructions they already possess about the natural phenomena we want to teach. Fortunately, this is now a strong field of research in science education, and many of its findings are available. Again there will be an intense and interesting competition if the support teachers need for this type of pedagogy is to get its share of the new science projects' resources.

Learning in Science

Let us consider briefly what we already know of the shape of the new era of science curriculum development, and apply to some of its projects the criteria I have developed for Science for All.

New Zealand science educators in recent years have contributed greatly to our understanding of how children learn science. Unfortunately, in using this as a base for reforming their science curriculum, the New Zealanders seem to have confused science content that was useful to elucidate these learning processes with content that is worth learning as Science for All. Their emphasis on preconceptual knowledge as the learning of worth in the compulsory lower levels of schools will, I am afraid, take its place alongside the conceptual processes of science from the '60s that have been such failures.

In the U.S., the new reform got off to a somewhat disastrous start from the viewpoint of Science for All. The National Science Foundation report on science education[1] that followed *A Nation at Risk* contained some rhetoric of Science for All, but its substance was about the improvement of elite technical education.

It is incredible that a report written in 1983 on the need for and role of science education could refer not once to the state of the world environment. It was as if acid rain, dioxane, and continued nuclear testing did not exist. It had, internationally, a somewhat offensive but perhaps nationally necessary subtitle about making American students' achievements in science education the best in the world by 1995.

This, of course, implies that American science education is not the best in the world now, and that is a refreshingly humble note on which to start. However, to which countries does the report look for its comparisons and targets? To Thailand, which seems to have solved the structural problems of science curriculums better than most and where girls do as well as or better than boys in chemistry and physics? To Tanzania and Kenya, where the idea of personal technology is being used very effectively in school science curriculums? To the Netherlands because they are in the forefront of relating physics learning to society? To Nepal and Sri Lanka, where elementary school science is being used as an effective instrument to enhance the lives of entire families?

No. The comparison that the NSF report contains has a strong sense of déjà vu about it. It is 1957 revisited, but the comparison now is not with the Soviet Union but with Japan, because of the technological and economic threats the Japanese are posing for the U.S. So much for Science for All.

I have not examined in detail all the new curriculum projects that have been sponsored by the National Science Foundation. One entitled Project 2061 does have a strong emphasis in its rhetoric on Science for All. Alas, its mechanism and procedures seem to be yet one more attempt to use the processes that failed in the 1960s. Teams of scientists (excluding science teachers!) are being brought together to try to answer from their blinkered perspectives, "What science do students need to learn?" No nonscientists are included; there is no voice from the many successful people in the U.S. who, in scientific terms, are scientifically illiterate. There is no voice of the dispossessed. It appears again to be a well-intentioned look outward, from well within the corpus of science.

The Secondary Curriculum Review in Great Britain has used as its basic source of ideas and pedagogy the exemplary work of innovative science teachers who have been successful with broader groups of students. This approach seems to have a better prospect of tapping into those outside-of-science views that I see as essential for Science for All. The greater problem for that country, with its propensity for social stratification, is likely to be how to provide recognition that this sort of science is important for all and not just an alternative for those who cannot cope with the "real" sciences of traditional school chemistry, physics, and biology.

Reading the Realities from Past and Present

Science for All is a vision splendid. Like any worthwhile vision, it recurs to lift the spirits of those who have become depressed with what they and others are achieving with current ways of doing things. In the 1930s, Lancelot Hogben's book, *Science for the Million*,[2] offered a vision to educators who began what has been called "the general science movement." In the late 1950s the vision came again and science educators tried again—as part of the science curriculum movement of the '60s and '70s. In the 1980s the vision is clearly before us once more. The shape of the responses to it in the next decade are now being formed. Their adequacy will depend very considerably on how clearly we can read the realities of the earlier attempts and realities of the very different social and educational situations of the current day.

A fundamental difference between the sort of science education (and hence curriculums) that we have had hitherto, and what may be needed for a genuine Science for All is the fact that the "All" must be thought of as existing outside of science. In other words, science is an institutionalized part of all our societies in very definite and varied ways. On the other hand, even in the most highly technical, scientifically advanced societies no more than 20 percent of the population could be even remotely identified with the institutionalized part. The remaining 80 percent are, and for their lives will be, outside of science in this sense. Furthermore, the 20 percent who may, or do, belong within the institutionalized aspects of science also spend much of their lives in spheres of society that are outside of science.

It is this sense of "outside of science" that I think we must understand and translate into curriculum terms if Science for All is to succeed from our present opportunities.□

1. The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, *Educating Americans for the 21st Century* (Washington, D.C.: National Science Foundation, 1983).

2. Lancelot Hogben, *Science for the Millions*, 4th ed. (New York: W. W. Norton & Co., Inc., 1968).

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