Una sección dedicada a innovaciones en la enseñanza de la química a nivel básico.

Science for All: Theory into Practice

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NOTA DEL DIRECTOR:
Después de reconocer y caracterizar los problemas que enfrenta una propuesta de Ciencia para Todos, el doctor Peter Fensham hace una serie de recomendaciones para poder transitar en esa dirección.

Muy provocativa, convincente e interesante resulta la tabla de nueve propósitos curriculares y el argumento de la imposibilidad de cubrirlos todos en cada nivel de la educación científica. En efecto, dicha tabla puede ayudar a generar propuestas curriculares a partir de un subconjunto seleccionado de propósitos. Lo mismo puede decirse de las estrategias pedagógicas internacionales que usa como ejemplos y su sugerencia de diversificarlas aún más.

Su clamor final hacia la búsqueda de un nuevo paradigma para la educación científica tiene mucho sentido como guía general de acción. Mucho habremos de construir y ampliar sobre ese EMPOWERMENT FROM SCIENCE para convencer y preparar a la sociedad, a las autoridades y a los profesores de ciencias de cada país, para llevar a la educación científica por este otro sendero.

Science for All (or a variation of it) has been so widely used in the last decade as an indicative slogan for a renewal of interest in school science that the importance of what is intended by it needs no further justification. Its official appearance dates from 1983 when it was chosen by a group of educators in the Asian Region of UNESCO as the title for a report. In it they argued successfully that a priority of funds and resources should be given by governments of the region to new efforts to make science education, at all levels of schooling (and outside school via the non-formal sector), valuable and meaningful to all students and their families.

In 1984, the Science Council of Canada reported on a four-year study of school science in that country. The title was *Science for Every Citizen*. A year later the Royal Society in London published a manifesto, *Science for Everybody*, as part of a larger report on the public understanding of science. In 1988, Australia's Curriculum Development Centre put out a national discussion document entitled *Science for All?*; and in 1989 the American Association for the Advancement of Science summarized phase 1 of its Project 2061 under the title *Science for All Americans*.

Since each of these uses of the slogan was associated with a call for major future action, we can rightly assume that *Science for All* refers to a problem about current school science. It is not the title of complacent accounts of past and current achievements.

In this lecture I shall attend to four aspects of the problem of Science for All:

I Recognition of the Problem
II Symptoms of the Problem
III Diagnosis of the Problem
IV Moves to Solutions of the Problem.

Each of these aspects has depended on research studies. The **Recognition** and the **Symptoms** involved analyses of existing data such as enrollments and survey analyses of sometimes simple and sometimes elaborate design. The **Diagnosis** has depended on historical and sociological studies of curriculum, content analyses of curriculum documents and materials, clinical studies of students and case studies of teachers. The **Move to Solutions** has added longitudinal studies and collaborative action research between teachers and researchers to the now much richer range of methodologies that exist for the study of science education. In what follows, I am largely reporting the essential findings of this research as it relates to *Science for All*.

However, before I embark on this research-based analysis and discussion, I need to acknowledge that the idea that science education should be rewarding for all school students is not new. It was commonly heard in the 1960/70s, and a number of the second wave of projects—following the senior science ones of the National Science Foundation (USA) and Nuffield Foundation (England)—were aimed at the students in elementary or lower secondary schooling. At that time science for all students could be described as a hope, and the extent of the extinction of that hope in practice can be measured by the contemporary call for Science for All. In the light of those relatively recent failures to achieve a similar educational goal, skeptics might well recognize Science for All as a theoretical possibility. This paper about *Science for All* as a hope, and as a social theory that can be put into practice is my answer to these skeptics.

I Recognition of the Problem

The present political and societal calls for *Science for All* to which I have made reference result from the presence in the 1970s and the 1980s of two very powerful underlying pressures.

The first of these to become internationally prominent stems from the wounded state of Planet Earth.

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"We live in a complex, dangerous and fascinating world. Science has played a role in creating the dangers, and one hopes it will aid in creating ways of dealing with these dangers. But most of these problems cannot, and will not, be dealt with by scientists alone. We need all the help we can get, and this help has got to come from a scientifically literate general public. Ignorance of science and technology is becoming the ultimate self indulgent word" (quote from Bernstein in Boyer's report, *High School*, for the Carnegie Foundation, 1983).

National and international awareness of the *Environmentale Problematique* developed very rapidly through the 1970s, following the UN Conference in Stockholm in 1972 on *The Human Environment*. Phenomena such as the pollution of land, water and the atmosphere, the profligate consumption of non-renewable material and energy resources by some, and the threats of extinction of many biological species became ones that politicians and societies at large could not continue to ignore.

Technological developments began in the 1970s to change the traditional economic advantages some countries had enjoyed. Their politicians were confronted with the issues of how to maintain their place economically in the face of these unfamiliar sources of competition.

"Our children could be stragglers in a world of technology in which technological skills and sophistication are the basic capital of tomorrow's society" (quote from National Science Board, USA, 1983).

The extent of this technological determination of society and particularly of its economic well-being was now so widespread that it was increasingly seen to require both a technological elite and more technologically capable citizens. "Technologically capable" was not now being identified with that earlier division of schooling into a narrow technical training for the many who were excluded from the academic education for the few who were to become elite professionals. Thus, the concern of a British manifesto, *Education for Capability* was summarized as:

"Young people acquire knowledge of particular subjects but are not equipped to use knowledge in ways that are relevant to the world outside the education system". (Royal Society for the Arts, Manufacturing and Commerce, 1986)

This not only criticizes the failure of traditional schooling, but also its successes because of the passivity of so much of the knowledge successful students acquire. It also defines "capability" in terms of the "use of knowledge in society beyond the education system".

There is a very widespread association in modern societies between Science and Technology. It goes far beyond the degree to which scientists and technologists (or science teachers and technology teachers) indeed identify with each other. This societal view of science and technology is reflected in the use of both terms in a number of the national reviews of the state of science education. In some countries where these reviews occurred, their results in the First International Study of Science Education conducted by the I.E.A. in the 1970s were available. They were alarmed, not reassured, by these international league tables of science learning achievement and no relief was available for them when the results of the Second Study of Science began to be reported in the mid 1980s. The international comparisons heightened for these committees of review the sense of concern that their more local investigations had aroused.

At best, these committees found, the participation in senior secondary science and the learning achievements through schooling may be supplying the demand (involving between 10-20% of each age cohort) for future scientifically-related professionals. A scientifically literate or technologically capable citizenry was certainly not being developed.

Similar concerns within education systems themselves had been developing throughout the 1970s, as a number of studies of the implementation of the new curricula of the 1960/70s were reported. In general, in countries where school districts had a choice, there was a disappointingly low level of uptake, rarely exceeding 25%. Where centralized control of curriculum existed so that implementation in one sense was 100%, the studies revealed that there were marked differences between the curriculum in practice and what was intended by its project designers. The difference was always a shortfall from the exciting view of the content that was intended for learning in the projects to a duller dogmatic set of conceptual knowledge and principles to be learnt by rote.

II Symptoms of the Problem

(i) The first direct symptom was the failure of the new science curricula, developed or adapted in many countries in the 1960/70s, to attract their share of the steadily rising proportion of each age cohort of students staying on for more years of secondary schooling. When the first of these new curricula were developed in the USA (with the support of the National Science Foundation) and in Britain (with Nuffield Foundation support), quite a small percentage of each age cohort in most countries completed all the years of secondary study. In Australia, for example, the figure was less than 20%, but about half of this elite group of students studied physics and chemistry (with associated mathematics). By the end of the 1970s, the proportion completing schooling had doubled, but only one third were now studying these physical sciences. By the end of the 1980s, the retention rate had almost doubled again and now less than one quarter were studying these physical sciences.

(ii) This unattractiveness of those sciences which were the foundations for students wishing to go on to scientific careers came, in the 1980s, under the scrutiny of the international women's movement. It was apparent that girls were a major group among the non-participators. It is true that in some Asian and East European countries girls were more equally represented, but this was in situations where the choices, to cease the study of the sciences or to study biology without chemistry and physics, were not allowed.

(iii) In a number of countries, in the 1980s, as the competition to obtain entry to the more attractive courses at more prestigious universities increased, it became evident that high achieving science students at school were moving to non-science programs in higher education. Law, business studies and computer science programs were being chosen by students who, a decade before, would more likely have chosen to study scientific and technological courses.

(iv) The effect of the relative unattractiveness of the physical sciences, and of the failure to continue with science studies is now, and has, at times in the last twenty years, seriously weakened the adequacy of the supply of scientific and technological expertise in a number of developed and developing countries.

(v) Particularly in the 1980s there have been a number of surveys that attempt to assess the scientific literacy of citizens as a whole. In Britain, Germany, USA, New Zealand and Australia, for example, the levels of literacy have in general been found to be low, with disappointing residues of school science knowledge.

(vi) Attitudinal studies of students towards science at school have revealed considerable expectancy as they move from elementary school to secondary school. However, these sorts of studies also find that substantial disillusionment often sets in after only one or two years of study of science in secondary school. Furthermore, among the students who do continue with science, there is a decline in attitude rather than growing enthusiasm.

(vii) Students preparing to become elementary school or early childhood teachers are a significant group from the more successful, "non-science" students at school. Many of them may have studied biology in the senior secondary years but, in countries where the choice exists, few have studied the physical sciences. Studies of these future teachers have shown that, as a group, their sense of knowledge of science and their lack of confidence about things scientific seem to be more determined by those physical science subjects they have not studied, than by the biology or earlier general science they have studied in their schooling.

III Diagnosis of the Problem

Diagnosis has involved research on two fronts or at two levels of the curriculum. The first involves individual students and teachers and the interactions between them in classrooms. The second is at the system level where decisions about the content of science to be covered are made.

There is now a very large body of evidence that many students have naive ideas about science phenomena (or alternative conceptions) that they bring to school science. Furthermore, these ideas have largely been ignored by science teachers as they present the school textbook view of the science topics in the curriculum. As a result we now know that, for many students, school science, if it is learnt at all, is learnt as a thin veneer of knowledge on top of their naive ideas, which remain largely unaffected even by prolonged experiences of school science.

The scientific knowledge that students do acquire is very often quite fragmented, that is, the facts and concepts and principles are learnt in very limited contexts that are not seen as associated with the natural or technological world outside school. More is learnt about ideal gases than real gases, frictionless worlds than everyday ones, Mendelian ratios than inheritance in human families, etc. More emphasis is put on using relational formula as algorithms than on why and what the relationship implies.

The everyday experiences of students are not drawn on as a base and context to deepen their understanding of science nor are they challenged by its abstractions. I remember a Year 7 student in North America who, knowing that aluminium boats floated when pushed out from the shore to the deeper water, related the sinking of an aluminium cube in a measuring cylinder in the teaching of "density" to the small amount of water in this "silly little cylinder"!

Most of those who developed the curriculum projects of the 1960/70s believed that the processes of discovery, invention and experimentation that characterize scientists' activities should be part of school science. In practice, analyses of the tests and examinations education systems used to define the "knowledge of worth" indicated that such an open and dynamic view of science is rarely evident.

The number of topics to be covered in each year (and the multiplicity of associated concepts and principles) is so great that anything other than a superficial coverage of them is very difficult. School science becomes a convergent subject full of right answers to be remembered. As Professor Dudley Herschbach, 1986 Nobel Laureate for Chemistry, said:

> "For example, in our science courses, particularly in elementary courses, students typically have the impression that it is a question of mastering a body of knowledge that's been developed by their ancestors. What really matters is being right or wrong in Science above all. I like to say to my students that in Science we are happy when we don't under-

stand. Any way we can encourage our students to see that in Science it's really not so important to be right or wrong, but to try excursions in thought whether they are right or wrong. Because, I emphasize, the truth will wait for you" (from Swedish TV interview with Nobel Laureates in 1986).

The justification for so much content in each year of school science is that it prepares the student for the next year of school science. In other words, the criterion for the choice of content stems from the demand to produce the scientific elite, not from the needs of scientifically literate citizens.

Content analyses of curriculum materials such as textbooks have revealed a number of biases against a number of groups of students. For example, gender biases against girls are pervasive and common. The contributions of women in Science are underplayed. The applications of Science are ones that male students (or some of them) can relate to more easily, and the assessment procedures (so often multiple choice) do not encourage the more fluent and discursive abilities of girls.

In many countries, as secondary education proceeds, students can make choices about whether to continue to study Science and which sciences to include in their upper secondary years. These choices have led to large numbers of students in the senior years not studying Science at all and to a preponderance of girls in biology and of boys in physics, with a more even balance in chemistry. Thus, there are large numbers of girls studying biology alone and conversely boys taking physics and perhaps chemistry but not biology. This means that many students, who have continued with some science studies at school and may have been successful in them, have very large gaps in their familiarity with, and confidence about, the spectrum of biophysical knowledge that underlies so many aspects of being a citizen in today's world.

IV Moves to Solution

New Content for New Purposes

A major breakthrough in moving towards a solution has been the recognition that the curriculum needs for mass science education are different from those for an elite preparatory science. Hitherto, in the earlier curriculum projects (and indeed still in some of the current national and state ones) it has been assumed that the same science education could somehow serve both needs.

Douglas Roberts in Canada pointed out in 1982 that seven quite distinct curriculum purposes or emphases can be identified in science curricula. Each will require, if it is to be achieved, its own selection of content and teaching and learning strategies. Some of these combinations are so different from each other that their fulfillment in school science will require a choice between

Table 1: Curriculum Emphases and the Two Outcomes for School Science

Future Scientific Professionals	Scientifically-Literate Citizens
Solid Foundations Correct Explanations Structure of Science	Everyday Coping Science, Technology and Decisions Science for Nurturing
Scientific Skill Development Science in Making Self as Explainer	

them. In other words, they are competing emphases and need to be recognized for their difference. Hence, a curriculum for any level of schooling cannot have seven emphases. Some will dominate at the expense of the others.

In Table 1, I have listed Roberts' seven emphases and two more recent ones under what may be their priority for the two outcomes of school science that Science for All now recognizes as equally important.

The recognition that curriculum purposes other than those of *Solid Foundations* and *Correct Explanations* need emphasis in the design and implementation of science education has been followed by several new models of curriculum that are more consistent with the three emphases in Table 1 that are primarily for students to become scientifically literate citizens. Salters Chemistry and Salters Science for the 13-16 age group in England set out "to start with material and phenomena familiar to this age group from their own experiences, or from TV and books". The science concepts are only introduced when they are needed to make sense of these experiences. Units called **Clothing, Drinks, Food, Buildings**, etc. are thus the topics in Salters Chemistry—a giant step from Gas Laws, Elements and Compounds, Acids and Bases, and Organic Chemistry.

The Physics Curriculum Development Project (PLON) in the Netherlands was perhaps the first of many now to use a **Concepts in Contexts** approach. Each of its units leads to a study of a set of concepts that are presented and make sense of a real world network of contexts such as **Living in Air, Bridges, Reproducing Sound, Traffic, Sports.** As aspects of these contexts are explored the concepts are found to relate to each other in recurring and novel fashions. The contexts make sense of the concepts, and the concepts in turn make sense of or add meaning to the students' appreciation of the contexts.

Logical Reasoning in Science and Technology (LORST) is a science curriculum for use in grade 10 in Saskatchewan, Canada. It raises a series of decisions, personal and communal, that need to be taken about the relationship between the consumption of alcohol and driving a car. The relevant chemical, biological, and physical knowledge is taught and related to the potential the students have to think about, and make these decisions.

Thanks to a number of pieces of research there is now much greater understanding of why school science has been unattractive to so many girls and, indeed, to many boys as well. Curriculum topics that encourage the "nurturing" role of Science for people and for the environment have been developed in a number of countries. Pedagogies, like creative writing, role playing, games, etc., that acknowledge the links between the affective and the cognitive and like the use of socio-scientific issues, where moral dilemmas are always present, are likewise expanding the attractiveness of school science.

There has also been a response in a number of countries to the realization that "the more choice **in** school about Science, the less choice **after** school". Thailand for example made its science-stream students in grades 10, 11, 12 study biology and chemistry and physics in each year, and its humanities-stream students take two years of physical and biological science. As a result, in the large school system in the Bangkok area, Thailand became the first country in the world in which girls participated and performed equally with boys in physics, and out-performed them in chemistry. This structural approach to *Science for All* is now being followed in a number of countries, although there are many others, including my own, that have not heeded its lessons yet.

New Pedagogies

The research studies of students' and teachers' conceptions of science and science teaching have involved a number of data collection procedures that have, in subsequent studies, been found to be very effective strategies for learning.

Two examples are:

i) The sharing between students of their conceptions and using these as the starting point from which the teaching and learning develops.

ii) Concept mapping, in which students are encouraged to state the relations between science concepts they have been learning, reinforces students' abilities to recall them and to use them in problem solving.

Many science teachers have been in the habit of using only a small number of teaching/learning strategies. Now a large number (more than 50 have been reported in Australia in the last decade!) are increasingly available to them. A number of these new strategies like the use of creative writing, project work, and co-operative learning have been very successful with, hitherto, disadvantaged groups, and less successful students.

The incorporation of these more inclusive strategies for learning Science into textbooks has not as yet proceeded very far. I am, however, familiar with the **Science Plus** series in Canada, and a few text that have incorporated some of them in a most attractive way for students. For example, the authors of **Science Plus** 1 begin one of its topics with explicit acknowledgment of the range of ideas students commonly present when asked about living and non-living things. The text for this topic asks many intriguing questions of its students that are not answered in the book (not even at the back!). Many novel exercises, that are set in the students' world outside school, seek and reflect the opinions and reasoning of the student readers. The range of activities is less stereotyped than in most texts. "Trivia" questions with appeal have been chosen to encourage the use of other source materials, and there are many challenges to the students to relate content in the book to every-day situations.

Even less developed so far are approaches to assessment of science learning that encourage a sense in students of personal involvement in the adventure of Science. Nevertheless, there are some exciting signs that this all important area of assessment is changing. In British Columbia, problem solving in shared scientific contexts is being encouraged in elementary science by tests that emphasize these skills. There are now, thanks to a group at the Australia Council for Educational Research, some very attractive paper and pencil tests that enable the conceptions students hold about scientific phenomena like Energy, Light, Chemical Reactions, etc., to be obtained.

A New Paradigm

I would like to finish by summarizing all these moves towards a solution for how to make school *Science for All*. To do so, let me remind you of the paradigm for school Science that has been the dominant one until recently. It has assumed that the teaching of Science at school is a process of INDUCTION **into** SCIENCE. Science teachers attempt to carry their students along the pathway they themselves trod earlier that ultimately leads to a scientific professional. Most science teachers only got a certain distance along this pathway, but they travelled it much further than did almost all of their own peers at school. Not surprisingly, they now find the task of carrying 25-30 students in more affluent countries, or 40-60 students in others, is too great, and most students are dropped or drop off and cease to travel with their science teachers.

Science for All (and the moves to its solution) requires a quite different paradigm. This one sees the students, as they move through the years of schooling, located in a developing set of social environments that becomes in late adolescence more and more like those in society that older citizens experience. Each of these social environments during the years of schooling involve aspects of Science. The science teachers' task now is to use his/her familiarity with the world of Science to gather and bring to the students the knowledge and skills from the vast corpus of Science, that will empower them with respect to these out-of-school situations. It is a process of EMPOWERMENT FROM SCIENCE. When we allow this paradigm to be the guide for our choice of Science content and pedagogies for school Science we may well indeed achieve SCIENCE FOR ALL our future citizens.

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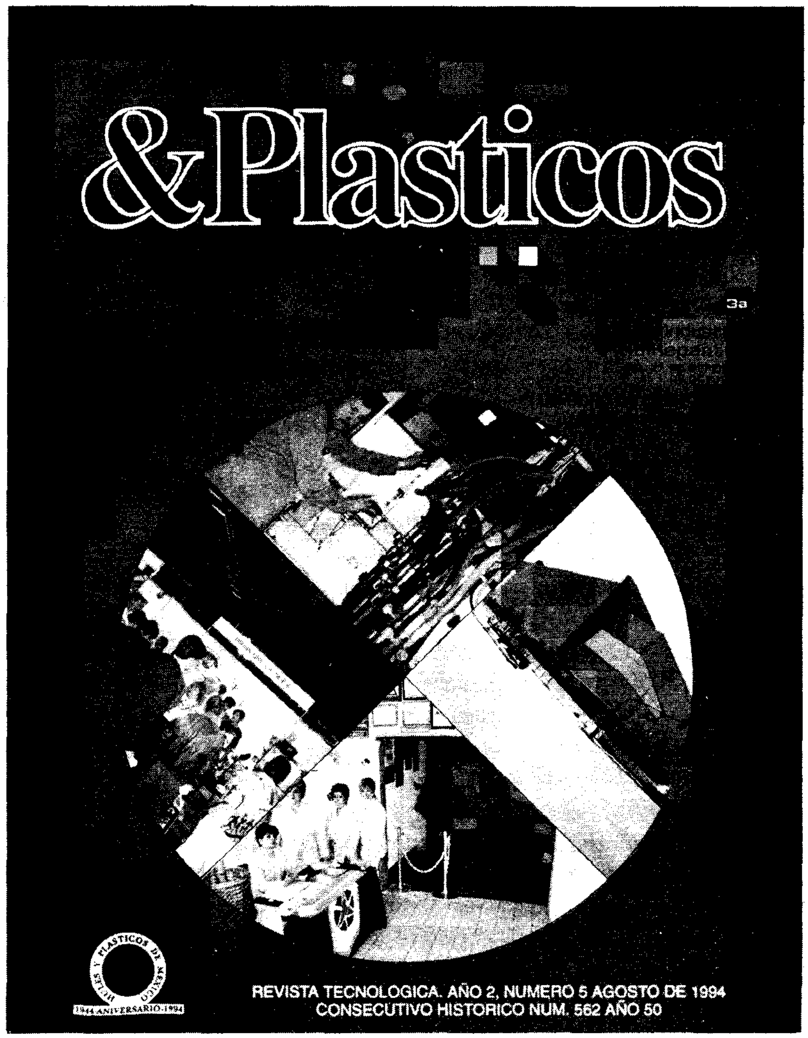

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