THE SCIENCE OF EDUCATION AND EDUCATION IN SCIENCE

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Whenever science and education are the subject of a conversation, assumptions are readily made and by precisely those who should not make them readily. Such conversations usually take place among educated people, who just because they are educated are certain to know what education is. And, unfortunately, those with a scientific education seem to be absolutely certain that they know what science is. Almost all educated people have received their higher education in colleges or universities that boast of a department of education. There all faculty claim that education is a science. The situation would not be so bad if they merely claimed that the teaching of education can be a reasoned discourse. That there is plenty of unreason in that discourse may be suspected from the ever more rapid revisions of syllabuses issued by departments of education. Ever new courses are introduced and ever new methods are being invented about the most effective methods of educating. The result is that the science of education resembles ever more closely a machine devised to produce illiterates in ever larger number.

It has become an educational fad to ask those still in elementary schools to write research papers. Pupils now have access to limitless information through the Internet but their teachers show no concern whether their youthful charges can make an informed judgment on what they are expected to research. It has become a fashion to let children in kindergarten graduate in cap and gown. After high school attendance was made compulsory two or three generations ago, the level of instruction in high schools began to sink lower and lower, with inevitable consequences for college and university education.

Even the best schools are not immune to this process. About fifteen years ago a course in creative English writing in the graduate school of Princeton

University had to be supplemented by a remedial course in creative English writing. Efforts to expose science students to courses in the humanities remained as ineffective to produce balanced minds as were courses that offered physics for poets. The method did not alleviate the situation which Schrödinger described half a century ago. In discussing the results of "an all around good scientific education", Schrödinger spoke of "the grotesque phenomenon of scientifically trained, highly competent minds with an unbelievably childlike-undeveloped or atrophied-philosophical outlook".[1]

It is said that America is run by the graduates of its best fifty or so graduate schools. Its many thousands of colleges merely produce such who, once they are hired by business or industry, can be taught there how to do this or that. Big industrial firms are increasingly uneasy about this development as they realize that they cannot simply assume enough competence on the part of those whom they hire for higher than mere quasi-manual jobs. It even happened in various countries that large industrial firms had set up their own examination for those who looked for a job with a Ph. D. in physics or chemistry in their hands.

In 1888 the emperor of Germany urged that gymnasia there should produce not Romans and Greeks but Germans. Undoubtedly there was too much Latin and Greek in the curricula but whether it was better to drop these subjects entirely should seem doubtful. By 1888 two centuries had gone by since the first battle between the "ancients" and the "moderns" took place, with more such battles to follow. The "ancients" stood for the age-old classical education, the "moderns" for the study of the new sciences. In 1868 T.H. Huxley attacked literary education as being largely useless and extolled the usefulness of courses in the various sciences.[2] About the same time Herbert Spencer wrote the most lopsided praises of science as the sole security in every facet of life.

In the middle of the twentieth century C.P. Snow did the same though rather deceptively. He did so in his Reith Lectures broadcast by the BBC, lectures that came out in print under the title *The Two Cultures and the Scientific Revolution*. At that time few noted the deceptiveness of Snow's endorsement of both cultures, literary (or humanistic) and scientific.[3] Many

[1] E. Schrödinger, *What is Life? and Other Scientific Essays* (Garden City, N.Y.: Doubleday, 1956), p. 96.

[2] For details, see my essay, "A Hundred Years of Two Cultures" (1975), reprinted in my *Chance or Reality and Other Essays* (Lanham Md.: University Press of America, 1986), pp. 98-118, and its sequel, "Knowledge in an Age of Science", ibid., pp. 119-43.

[3] See my essay, "A Hundred Years of Two Cultures", as quoted above.

in a West overawed by Soviet propaganda, readily swallowed Snow's argument which ran along the following line: Of the two main branches of cultures, literary and scientific, the scientific is the voice of the future. To prove this, he first offered a few anecdotes about early nineteenth-century Oxford dons who failed to see the future so much as to deplore the running of trains into Oxford and certainly on Sundays. Since men of science did not make such objections to trains they had, according to Snow, the future in their bones, a strange argument to prove the positive from the negative. Snow then claimed that among scientists experimental scientists showed a better grasp of culture than theoretical scientists. Among experimental scientists engineers were the most alert to the needs of mankind. Finally, since the Soviet Union produced many more engineers than the West, the future belonged to the Soviet Union. Such was a stupefying Gleichschaltung of two cultures or of any culture for that matter and of any education worth being called education.

The only saving grace in Snow's lucubrations was that he avoided saying what he meant by education, whether literary or scientific. Had he considered the etymology of the word "education", Snow might have had some second thoughts, but probably none at all. The ideology he stood for relied heavily on the art of skirting the basic issues, even the basic meaning of words, which is often revealed by their etymology. The word education comes from the Latin verb *e-ducere*, which remains a mere word, unless we consider what is being "e-duced", or drawn out, and from what it is being elicited.

In other words, to make the word "education" meaningful one has to consider the subject and the object of the very act of educating. The subject of education is the pupil, presumably a human being, although nowadays they often behave like little beasts, overstimulated as they are by the marvels of technology. Whether they are humans or are beasts, education takes them for mere specimens of a species which is to be instructed by lessons learned from observing the behavior of this or that animal species. The object of education is what is being drawn out from the subject.

Compared with these two notions, the object and subject of education, quite secondary should seem the manner or the technique of the procedure, or the educational skill, which often passes for the art of education. As long as those two, the subject and the object of education, were in the focus, and not the technique or skill of educating, no one assumed that the student, the pupil has a built-in fund of information, a fund born with him, so to speak, that can be cajoled out of them. It became the dubious privilege of education in recent decades to take education for magic whereby one can prompt the student to rediscover the rules of mathematics and the rules of grammar, and even the skills needed for the various arts, such as drawing. Luckily they are not encouraged to compose music. They are, however, being taught that computers can take the place of composers. So they are hardly encouraged to care about learning music, which, however, was a principal branch of classical liberal education. Rock music is literally rocking our culture. Casettes with animalistic singing have become runaway bestsellers and this in university campuses as well. A brief walk by a typical college dormitory provides more than enough evidence.

At any rate there is much truth in the observation about the respective function of the three main branches of college education, the administration, the faculty, and the students. Now students want to teach, the faculty want to administer, and the administration is supposed to get the money for the farce of turning education upside down. Education is rapidly degenerating into the art of conveying all sorts of skill.

There can be no question about the fact that ever since Comenius, who is often taken for the first modern educator, much more emphasis has been laid on the technique of teaching than on what is being taught, and hardly any attention is paid to the subject of education, or the pupil himself or herself. This is even true of what was said on education by Pestalozzi, by Herbart, by Montessori, to mention only a few of the big names of the history of modern education. Fifty years ago anyone with a college degree in mathematics could apply for a job to teach it. The same was true of other subjects as well, such as Latin, or geography, or history. By the late 1950s it was required that applicants for teaching jobs have more courses in education than in the particular subject they wanted to teach. Skill nowadays wholly dominates substance.

Obviously it cannot be the purpose of education to draw out data of information that are simply not born with the student. Man is born as a “tabula rasa”, although a very strange “tabula” or board or rather drawing board. Pieces of information can be drawn on that board which is very different from a purely material board. On a material board one can draw lines of various forms, but many such lines will appear on that “tabula rasa” as concepts corresponding to written or spoken words, all of which are universals. It is therefore most illogical to take the students for a purely empirical or material being, for just one specimen of a species which is just one among millions of species. It is illogical to try to educate little children in the manner in which animals are thought to learn if the human species, alone among all species, is able to form concepts (which comes from the

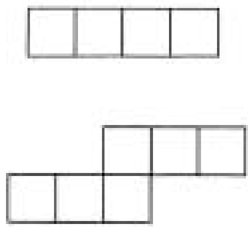
Latin word “con-capere”), that is, to grasp the universal in the particular. Each and every human word is a proof, including words uttered by professors of education who do not want to come clean on the issue as to what they take human beings for. And since they dissimulate, they would deserve to be dismissed from their chair. There is no tragic harm in holding any view, if the view is held openly. The irremediable harm is dissimulation that should be considered a form of crime committed against humanity.

But back to concepts which are very supple items and as such they wholly escape material representation. Only words corresponding to integers can be represented say by a figure of definite contours, such as a square. And these words represent only a minuscule part of words used in any developed human language. Integers are practically infinite in number, but it is enough to know numbers up to ten to know what is two hundred-twenty-four, or three million and twenty. Strangely enough, the drawing board, the “tabula rasa” of a human pupil will catch on readily with the meaning of a practically infinite number of integers, most of which have not been verbalized to him.

Now the meaning of a given integer can be imagined as the juxtaposition of the same number of squares. Not so with the visual representation of the meaning of any other word. Any such word is defined in terms of six or seven or more other words, and none of these have a meaning with a definite contour. Their partial overlap forms an area which is again without a distinct contour. Moreover, the meaning of words continually change, but, unlike amoebas, words do not have a membrane. For amoebas to live, they must remain within the membrane. Words live only as long as they are not given exact contours. Words may be best compared to patches of clouds. Looked at from a distance, they, or at least some clouds, may appear with a crisp contour, but as one gets close to them, say by flying, one does not know the exact place and moment when one enters them (see Figure 1).

Now classical education was in a sense the imparting of a skill to handle patches of fog. This perception is still to gain grounds. It first appeared, so it seems, in a paper I gave six years ago before the 10th World Congress of Optical Engineers held in Orlando, Florida. I doubt that more perhaps than a few of the tens of thousand of members who received the Proceedings of that Congress cared to read my paper there and consider the figure which I have just showed. Most of the three thousand or so attending that Congress showed interest only in technical solutions to problems arising in optical engineering. They work with quantities and they know that quantities work and do work marvelously. The Bible already said that God dis-

**Representation by areas,
all with precise contours,
of the definition of the meaning of integers.**



**Representation by areas of the definition of the meaning
of non-numerical concepts when the definition consists of three words.
The area where all three overlap to define such a concept is marked 3.
Areas where only two areas overlap are marked 2,
and areas where there is no overlap are marked 1.
Note that no area can have a precise contour.**

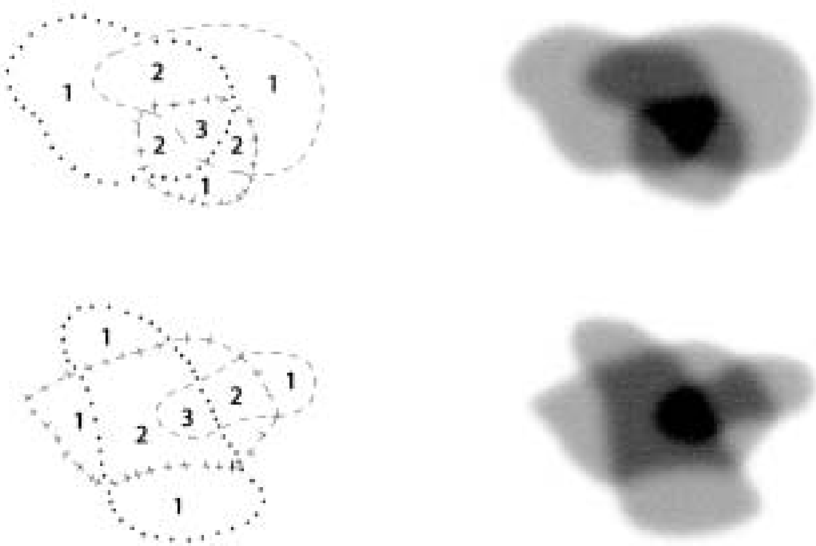


Figure 1.

posed everything according to measure, number, and weight. Tellingly, this phrase comes from the Book of Wisdom and was, during the Middle Ages, the most often quoted biblical phrase. Just one indication that those Ages were not so dark after all.

But one would look in vain in the Bible for a most fundamental point about numbers, or at least for a very challenging point about the realm of numbers. Well, the Bible is not a philosophy book, let alone an interpretation of the foundation of mathematics. The point is that one needs non-quantitative words, or words that are not numbers, in order to give the definition of even the simplest class of numbers, the integers. The proof of this is any dictionary of any language. Those who rather believe an eminent mathematician, there is Hermann Weyl, who wrote: "One must understand directives given in words on how to handle the [mathematical] symbols and formulae".[4]

When we try to define imaginary numbers, we have to give up our imagination, which can imagine a square, or a circle, but not a number which is imaginary. This is not the only strange feature of the human mind, which is to be educated. Another is that we do not become irrational when we talk of irrational numbers, although they cannot be visually represented. We talk of the exact sciences and we are confident we know what we talk about: empirical sciences cast in the terms of mathematics. Still the meaning of the word "exact" cannot be given with an area of exact contours. The only way of coping with this conflict is to trust the ability of the human mind to have insights that are clearly non-empirical.

But before I say something of the importance of including some such considerations in scientific education, let me go back briefly to the classics or rather to classical education. It would be nonsensical to think that the story of the Horatii and the Curiatii was drilled in the minds of young boys as if they were ever to find themselves in exactly the same situation as those famous Roman heroes. Those stories were subtle patterns, consideration of which was to generate intangible insights.

Those stories were picked from a distance of many hundred years and as such they did not generate political animosities. Even today stories about Lincoln cannot be taken for a pattern because they are just too close to us. Lincoln is not a wholly uncontroversial figure in the Southern parts of the United States. Participants from other countries will find their own exam-

[4] H. Weyl, "Knowledge as Unity", in L. Leary (ed.), *The Unity of Knowledge* (Garden City, NY: Doubleday, 1955), p. 22.

ples from their not too distant past to illustrate the need for going far back into history to find apparently uncontroversial patterns of behavior. But we must find them or else education will become the imparting of mere technical skill even in the humanities. In the sciences education has hardly ever been more than the imparting of such skills.

Communication is now a science, I would say the skill of misinformation. A journalist must know the technique of how to escape the charge of editorializing in the guise of reporting. The simplest form of that skill is to find somebody who agrees with the position of the newspaper and ask him or her for opinion. This then is reported as being representative of the thinking of society at large, but it reflects above all the view of the editor and perhaps also of the reporter. The technique is a skill in the art of lying about which most reporters and editors as well as professors in schools of journalism are not really concerned. No room there for an Augustine of Hippo, who on thinking ever more seriously about becoming a Christian realized that his profession, for which the State paid him, was to promote lies. This dawned on him when shortly before his conversion he was supposed to deliver an oration on the emperor's birthday. He knew that, like other rhetors paid by the State, he had to lie from both corners of his mouth by presenting a rascal as a paragon of virtues.

I am not saying that such an art is explicitly endorsed in our schools of education, but it is hardly met head on, because there everything has to be politically correct. There the chief aim is to make everybody feel comfortable with anyone else's views and pattern of behavior. The result is that modern society is coming apart at the seams. Statistics on crime, on deviant behavior, speak louder than words. The science of education has become an instruction in brazen pragmatism.

Education in science has hardly ever been more than the art of imparting computational skill and skills in experimentation. Most Ph.D. graduates in physics have never been asked to take a course in basic epistemological or ethical questions, although they meet them at almost every instance. They face up to them only when they pick up books by this or that prominent physicist who waxes philosophical in old age and all too often just rediscovers age old errors in philosophy. I cannot forget the surprise of my late dear friend Eugene Wigner who once showed a philosophical paper of his to a friend of mine who happened to know the history of philosophy. In that paper, of which Wigner was very proud, he had merely rediscovered the old system of Ockham and Malebranche, the system called occasionalism.

To his credit Wigner conceded the point of not having discovered anything new, but he would not admit that what he had rediscovered had long been refuted on purely philosophical grounds. He thought that science vindicated occasionalism. He merely confused the good science of quantum mechanics with the bad philosophy Bohr, Heisenberg, and others grafted on it. The two now form a unit about which it is not supposed to ask whether it is put together from two parts, one good, the other bad. The unit is being taught as an indissoluble whole, with some frightful consequences.

An instance of this is the rejoinder which a Caltech Ph. D. candidate in quantum cosmology voiced on hearing my remarks on creation out of nothing. According to him I was wrong in claiming that the nothing is nothing and not something. He claimed that quantum mechanics proved that the nothing at times was something and vice versa. I merely suggested to him that he should inform his bank about this astonishing development. The astonishingly facile style in which prominent quantum cosmologists claim that quantum cosmology enables them to create universes literally out of nothing, or that the metaphysical idea of creation out of nothing has now become a proposition to be experimentally decided by physics, is a piece with that rejoinder. Cosmologists would do well to take seriously an observation which one of them, L. Landau, had made about them: "Cosmologists are frequently in error but seldom in doubt".[5]

My question is then the following: In promoting scientific education what are we going to promote? Are we going to promote skill in solving non-linear equations with or without the help of computers, or are we to promote the spread of insane non-scientific claims dressed in scientific garb? I carefully avoided the terms insane philosophical claims, because if a claim is insane, it cannot be philosophical, although this restriction is no longer allowed among professional philosophers. No wonder that philosophy has become almost a bad word. More than a hundred years ago it was customary to say in German scientific circles: "Philosophie ist die systematische Misbrauch einer eigens zu diesem Zwecke erfundenen Terminologie", or in English, "Philosophy is the systematic misuse of a terminology invented for precisely that purpose". What those scientists failed to notice was that the only way to avoid philosophy, indeed metaphysics, is to say nothing.

It should be obvious that it is very philosophical to make a judgment about insanity, whether of a person or of an enterprise. At the dawn of the

[5] Quoted by C. Humphreys, of the Department of Materials Science in Cambridge University, in his letter to *The Times* (London), January 10, 1994, p. 15.

third millennium it would be utterly insane not to see mankind's total dependence on science. Science alone can keep us well-fed and healthy, and take us quickly to long distances. Science is indispensable for securing peace for mankind, although it has to do this all too often by making war. The construction of the Twin Towers of the World Trade Center would have been inconceivable without science, which is also true of their wanton destruction. It has indeed been estimated by structural engineers that had those hijacked planes hit the Twin Towers at their ninetieth floor or higher and not at their eightieth floor, those towers might not have collapsed.

But before I say more about the real and imaginary abuses of science, let me recall a statement of Samuel Johnson, the great codifier of modern English in the late eighteenth century. At that time gentlemen still wore lace around their neck, on their chest, and around their wrist. Of lace, Samuel Johnson said, one can never have enough. I would say the same about science: of science no one can ever have enough. Scientific education is a matter of survival and progress, apart from being a powerful source of satisfying legitimate intellectual needs to understand the world we live in. But it should not be allowed to turn science into a potential curse. This may be the case if scientific education becomes merely an art of imparting scientific skills. The product will be a scientifically trained class that will not know what to do with science when it comes to crucial junctures. That class will merely feel a non-scientific pressure, without the ability to cope with it.

Let me give you some examples from scientific history, because even in the history of science it is true what was stated two thousand years ago about history in general: History is philosophy teaching by examples. A historian has to be selective for a reason far more important than that readable books cannot stretch beyond three to four hundred pages. So let me select some examples from the history of science, because of their philosophical or rather educational instructiveness.

Half a century ago, the challenge was whether to make or not to make the atomic bomb. Once the war was brought to an end by the explosion of an atomic bomb over Hiroshima, second thoughts began to surface, partly for political reasons. But other reasons too did surface in the answers given by atomic scientists. John von Neumann simply said that he and others were simply unprepared for the philosophical and ethical challenges. We were, he said, like little children. Other scientists said that by making the bomb they proved themselves to be, I am quoting, "sons of bitches".[6] Still

[6] For details see my *The Relevance of Physics* (Chicago: University of Chicago Press, 1966), pp. 395-96.

others, Fermi was a case, claimed that the atomic bomb was just a piece of superb physics. But I still find most instructive as well as most frightening the reply Oppenheimer gave on being questioned by a Congressional Committee about whether some ethical considerations had been weighed before the making of the bomb. Oppenheimer replied: "...it is my judgment in these things that when you see something that is technically sweet, you go ahead and do it and you argue about what to do about it only after you have had you technical success".[7]

The words "technically sweet" are unparalleled for their expressiveness. Today they are reworded by those biochemists and microbiologists who want legal protection and indeed public funding for their program of cloning humans. This they request on the ground that there should be no limit set to satisfying scientific curiosity. Or take Steven Gould, who twelve years ago spoke of the devastation of AIDS as simply the mechanism of evolution which eliminates specimens of a species that possess less survival value than the others.[8] Surely this view is fully logical if one agrees with James Watson that genes are the only thing to know.[9]

About half a century ago Herbert Butterfield gave a much publicized lecture at Harvard in which he spoke of the teaching of the history of science as the subject that would replace the teaching of the classics as a basic framework of education.[10] Classics have already been largely eliminated from the curricula, but nothing yet has been chosen to fill the vacuum. Suppose, Butterfield's suggestion will be taken up. But then the question arises about the examples we are going to take from the history of science. Surely, Galileo will be taken up. But are we going to make it a part of that educational course in the history of science that Galileo praised sky high Copernicus's courage to commit a rape of his senses? But will an empiricist education tolerate this praise which flies in the face of John Dewey's empiricism that still rules American teacher colleges, beginning with the one at Columbia University?

Einstein is surely another one who will be taken up. But what is going to be taught about Einstein? The cliche, according to which he proved that

[7] See ibid., p. 397.

[8] S.J. Gould, "The Terrifying Normalcy of AIDS", *The New York Times Magazine*, April 19, 1987, pp. 32-33. See also my essay, "Normalcy as Terror: The Naturalization of AIDS", (1987), reprinted in my *The Only Chaos and Other Essays* (Lanham, Md.: The University Press of America, 1990), pp. 144-51.

[9] In a lecture at Princeton University, reported in *The Trenton Times*, Feb. 25, 1995, p. 1.

[10] H. Butterfield, "The History of Science and the Study of History", *Harvard Library Bulletin* 13 (1959), pp. 329-47, especially p. 331.

everything is relative? Or is his admission also to be taught that it would have been much better to call the theory of relativity the theory of invariance? Or is another admission of his also to be taught that he failed to derive from science even a drop of ethical value? Or is it also going to be taught that according to him it was not the uranium but man's heart that needed to be purified? And if education is a task to set role models, can an Einstein be chosen, whose biography, *The Private Lives of Albert Einstein*, written out from the Einstein Archives,[11] surely makes for a titillating text? Or is the teaching of the history of science to become a means to create the belief that scientific expertise puts one above basic norms of human responsibility?

Of course, Darwin, too, would be taken as the one who proved that everything is evolving and that man descended from the apes and that there was no purpose. About man's descent I hold something even more drastic, namely, that man's ancestors were the rats or other rodents, hundreds of million years older than apes and monkeys. But if rodents were our great grandparents, the difference between man and his ancestors is even greater than ever. What then becomes of the marvelous precept which Darwin wrote on a piece of paper as a constant reminder for himself: "Never use the words 'higher' and 'lower'".[12] Every page of the history of evolutionary biology shows that neither Darwin nor his disciples obeyed this very sound rule, sound at least from the viewpoint of the scientific method. That history should also teach Whitehead's observation made in 1929 with an eye on Darwinists: "Those who devote themselves to the purpose of proving that there is no purpose, constitute an interesting subject for study".[13]

That history should also teach the hollowness of Tyndall's dictum that "a mind like that of Darwin can never sin wittingly against either fact or law".[14] Well, Darwin kept under cover the fact that he took his main ideas from two papers of Edward Blyth, but he hoped that from a distance of twenty years none of the readers of *The Origin of Species* would remember those papers. In fact almost nothing was said on the subject for another hundred years or so. Then the subject surfaced again, but also quickly

[11] See R. Highfield and P. Carter, *The Private Lives of Albert Einstein* (London: Faber and Faber, 1993). Less explicit, though still very revealing is Schrödinger's major biography by W.J. Moore, *The Life of Erwin Schödinger* (Cambridge University Press, 1994).

[12] Darwin's motto placed in his copy of Chambers' *Vestiges of Creation*.

[13] A.N. Whitehead, *The Function of Reason* (Princeton University Press, 1929), p. 12.

[14] Address to the British Association, 1870, on "The Scientific Use of Imagination", in *Fragments of Science* (New York: P.F. Collier, 1901), p. 135.

dropped by admirers of Darwin as the one who could not “consciously tell a lie”. Such are the words of G.G. Simpson, the leading American Darwinist of the mid-20th century, who sought refuge in the lame claim that there “always remains something hidden [in Darwin’s life and character] as there is in every life”.[15] Yet, apparently only in some cases should this all-alleviating principle be applied. Even more revealing was the attitude, about the same time, of the geneticist C.D. Darlington, who said, in reference to the Blyth matter: “Among scientists there is the natural feeling that one of the greatest of our figures [Darwin, that is] should not be dissected. at least by one of us”.[16]

Loren Eiseley was not really one of them, although he wrote well about paleontology and did so as befits an unstinting admirer of Darwin. In presenting the full evidence about the Blyth matter, Eiseley claimed that the mystery of Darwin’s character cannot be solved.[17] In adopting this evasive stance, Eiseley simple reduced the amount of “new light”, which his book, according to its subtitle, wanted to throw on a very touchy subject. When a courageous historian of science decides to set forth matters with no holds barred, scientists are apt to be very resentful. The scientific community, so ready to canonize some of its members, still has to emulate the Catholic Church, which canonizes some of her own, though only with the help of an office popularly called the office of the devil’s advocate. About this, too, something should to be said in the education of scientists.

James Clark Maxwell, too, will be included in that list of great scientists, but hardly that Maxwell who wrote that “the most difficult test of the scientific mind is to discern the limits of the legitimate application of the scientific method”.[18] The first to glimpse the depths of this remark was Heinrich Hertz, the first to demonstrate the reality of electromagnetic waves. But Hertz was concerned with something far deeper. He wanted to know what Maxwell’s theory was. And here too a question that begins with the word “what” brought up philosophy. Hertz finally gave up the struggle saying: “Maxwell’s theory is Maxwell’s system of equations”.[19] That system, those equations were differential equations. The same could be said of

[15] G.G. Simpson in *Scientfic American*, August 1958, p. 119.

[16] C.D. Darlington, *Darwin’s Place in History* (Oxford: Blackwell, 1959), p. 57.

[17] L. Eiseley, *Darwin and the Mysterious Mr X* (New York: Harcourt, Brace, Jovanovich, 1979), p. 93.

[18] *The Scientific Papers of James Clerk Maxwell*, ed. W.D. Niven (Cambridge University Press, 1890), vol. 2, p. 759.

[19] H. Hertz, *Electric Waves*, tr. D.E. Jones (London: Macmillan, 1893), p. 30.

Newton's theory of gravitation or of Einstein's theory of reference systems moving at constant speed or accelerated with respect to one another.

But if one admits that science, in its most exact form, is merely a set of equations, then its limits come to the fore immediately. No scientist can avoid the use of universals, although mathematics gives no enlightenment on them, not even a handle on them. No scientist can avoid the use of the word *is*. To try to measure the *is* in centimeters or in nanoseconds is a patent absurdity. The scientist will then have to recognize that which Feynman did recognize, namely, that there is no philosophy of quantum mechanics, but there are only some quantum mechanical operators, all of them strictly mathematical. Bohr said pretty much the same, but he also said other things as well whereby he fully contradicted himself. Contradictions are bad enough, but not nearly as bad as plain hubris. Unfortunately when hubris is preached in the guise of science, few will protest. Protests from the scientific community are still to be heard about Bohr's claim that his complementarity theory will be the future form of religion and its only good form.[20]

Is education in science going to include some such points or will it continue to be an art of imparting skills in calculation and experimentation? The question is important in its own terms but also for a practical reason as well. That reason is simply the fact that to learn science demands today far greater effort and time than was the case fifty years ago, let alone a hundred or two hundred years ago. Even three hundred years ago, it was impossible for John Locke, surely an intelligent man, to master the latest in science, or Newton's *Principia*. As reported by Desaguliers, Locke asked Huygens whether the mathematics of the *Principia* was reliable. For if it was, so Locke thought, he could become "the master of all physics", by which he meant a Newtonian philosopher.[21] Today a mind of Locke's caliber has even less chance of mastering physics, unless he had been formally instructed in it. But the fact remains that only a fraction of educated men, with a good mind, can be educated in science.

The rest of mankind will have to take from scientists what science is. Is there going to be an education in science that would enable scientists to speak intelligently about science? Are there going to be enough scientists

[20] A recollection of A. Rosenfeld; quoted in R. V. Jones, "Complementarity as a Way of Life", in A.P. French and P.J. Kennedy, *Niels Bohr: A Centenary Volume* (Cambridge: Harvard University Press, 1985), p. 323.

[21] See the Preface by I. Bernard Cohen to Newton's *Opticks* (New York: Dover, 1952), p. xxii.

who would agree with Polykarp Kusch, a Nobel laureate in physics, who warned in 1963: "Science cannot do a very large number of things and to assume that science may find a technical solution to all problems is the road to disaster".[22] Such a road was charted a hundred years ago by Marcelin Berthelot, a famed French chemist of his time. He served as minister of education, then also as a minister of foreign affairs. He must have felt qualified for all such jobs since he had made in 1897 in a public conference on "Science and Popular Education" the following declaration: "People begin to understand that in modern civilization every social utility derives from science, because modern science embraces the entire domain of the human mind: the intellectual, moral, political, artistic domain as well as the practical and the industrial".[23]

Contrary to Berthelot and similar scientist worshipers of science, science does not embrace the basis of intellectual endeavor which is concept formation, nor many areas of that endeavor, that cannot be measured. Those who take the opposite view attribute to science wisdom which it cannot have in terms of its method in which the touch of proof and truth is measurement, a quantitative operation. To attribute anything more than that to science is the height of unwisdom.

Bernard Shaw once remarked that it took a monster to conceive of a Nobel Peace Prize. Unfortunately, there have become attached some monstrous aspects to the Prize in the field of hard sciences, among which I do not count economics. That such is the case is undeniable. Hardly remembered is the manner in which Eugene Wigner tried to keep at safe remove those monstrous aspects. On receiving the Prize in 1963 an army of reporters descended on him in Princeton, asking his view on questions that had nothing to do with his work in physics. He dismissed them by saying that the winning of the Prize did not make him "a man of wisdom" and that "it is a great danger if statements of scientists outside their field are taken too seriously".[24] There is indeed a very good ground for saying that young men and women aspiring to become scientists might learn a great deal of good humanities from studying the human side of science and scientists. A good exposure to the history of science would help provided the history is not a recital of legends, although they had been long exploded by serious historical research.

[22] Address to Pulitzer Prize Jurors, reported in *New York Herald Tribune*. April 2, 1961, sec. 2, p. 3, col. 4.

[23] See my *The Relevance of Physics*, p. 399.

[24] *The Daily Princetonian*, Nov. 7, 1963, p. 1.

This kind of research will be kept out of the reach of science students by precisely those scientists who, like the British geneticist C.D. Darlington, would say, as was noted above, that Darwin's dissimulation concerning what he had learned from Blyth, should not be dissected by biologists themselves. Yet when such dissections, almost vivisections, are performed by a historian of science, he is resented or dismissed as one who shifted from science to the history of science for not being able to prove himself as a scientist. Steven Hawking fell back on that defense on finding that a historian and philosopher of scientific cosmology dared to point out the philosophical *non sequiturs* that grace his *Brief History of Time*. Little can, of course, be done with scientists who want to form a society of untouchables. In that case they should remove themselves from the task of educating, a task very different from transmitting mere skills, however arcane, over which they alone have a mastery.

Education in science must keep in focus good and valuable non-scientific insights by scientists, because the scientific class has at its disposal means far more powerful than any other class and therefore its voice will be much more listened to. Then the further question will arise about the principles needed for the proper use of the means. If, however, scientists would teach society at large that everything is relative, or would condone such a teaching, society will then see in this a scientific proof of the proposition that all patterns of behavior are equally good. Then society will not be able to perform a critical and controlling role even about the non-scientific statements of scientists. Then scientists will be left on their own in full practical control of the means they have produced and which they alone can handle. All of us then will be faced with Juvenal's question: "Quis custodiet ipsos custodes?".[25] which may be rephrased as follows: Who will control those who claim to control the rest? Those who make that claim can merely claim that they alone have the skill, the know-how of handling some controls without being able to prevent that everything would get out of control.

Clearly, science will not give the answer, nor an education which is merely the skill of imparting knowledge, scientific or other. Education in science should therefore be much more than a technique of imparting skills. "Education is a high word", John Henry Newman said in his *Idea of a University*.[26] Only by rising high above the level of science, which is universally extended, though always on the same plane formed by quantitative

[25] Satire VI.
[26] *The Idea of a University* (Doubleday, 1959), p. 164.

relation, can we have an education in science which qualitative in a non-trivial sense. Newman was a theologian, whose business is to talk about God's ways of educating man. Here, before this Scientific Academy, it may be best to recall that nothing contrary, indeed something very similar, is contained in Schrödinger's observation: "Physics consists not merely of atomic research, science not merely of physics, and life not merely of science".[27] A perfect summary of what education in science ought to be. Otherwise, science may become one of the four S's of those universal wrapping papers which unable to sell anything. Three of those S's are Sex, Sport, and Smile. God forbid that science become the fourth of those dubious commodities, and also become the target of an unintended pun, as the plural of the letter s sound very similar to the sound of a word spelled a, s, and s. By trying to become scientific, theorists of education are removing an important barrier in the way of that disastrous development. Education in science has indeed a very great and serious task cut out for it, not only for man's sake but also for the sake of science.

In the wake of World War II, the Commission for University Reform in Germany, urged that each lecturer in a Technical University should have the following qualifications. The first two ought to be quoted verbatim: "1. To see the limits of his subject matter. ... 2. To show in every subject the way that leads beyond its narrow confines to broader horizons of its own".[28] On reading this, one would be prompted to state with Pascal: "All good maxims are in the world. We only need to apply them".[29] Unfortunately, qualification #1 is qualified with the following: "In his teaching [the teacher should display the ability not only] to make the students aware of those limits [but also] to show them that beyond those limits forces come into play which are not entirely rational, but arise out of life and human society itself".[30] There are, of course, forces at work in man and in society that are not entirely rational, but qualification #1 seems to suggest that reason is equal to science and science to reason and that whatever is not science is not entirely rational. This is, however, the number one danger to be avoided both in the science of education and in education in science.

[27] Unfortunately, I lost my reference to the provenance of this statement of Schrödinger.
[28] Schrödinger, *What Is Life? and Other Essays*, p. 115.
[29] *Pascal's Pensées*, tr. W.F. Trotter (New York. E.P. Dutton, 1958), #380.
[30] Schrödinger, *What is Life? and Other Essays*, p. 115.

SCIENCE EDUCATION AND INFORMATION TECHNOLOGY

MAMBILLIKALATHIL G.K. MENON

The very first aspect of the purpose of this conference it is to consider how science and technology permeate the educational system. We have an educational system and we want to see how science and technology percolate into it, and of course we are only going to look at the school primary and secondary education system. But there is an aspect that has repeatedly come up for discussion. Prof. Osborne raised it in particular when he discussed scientific literacy and it was also referred to earlier when science education and its relationship to the scientific information for the public was discussed. One is referring here to the whole area of science communication, or science for all rather than for specialists, and I believe this is an equally important area that we should consider because it is part of what emerges from the primary and secondary levels.

I would like to start by saying that the main area I would like to deal with is the scale factor in primary and secondary education, and this is because I come from India, which is a developing country. Professor C.N.R. Rao discussed certain categories of countries in his report about scientifically advanced, proficient, lagging and so on countries. There are many areas of development in India where India might be regarded as an advanced country, but let me say that if one looks at the overall picture, India is certainly a developing country as far as the area of primary and secondary education is concerned and as far as science education is concerned. Professor Rao made a very forceful and impassioned speech about the problems of development and the developing countries, so I will not repeat a large part of what he had to say, but if we are going to discuss the future, if we are going to discuss primary and secondary education and science education, and as I said the principal purpose of my presentation is to deal with the question of scale, I want to say that there are a very large number of issues across the spectrum, and these are seen essentially in the developing countries.

First of all, I know that in my country there was a promise made to achieve universal elementary education; there was a promise made in the Constitution of India in 1950. We still, in 2001, have not fulfilled this promise. There is the question of literacy. I am not talking about scientific literacy; I am not even talking about the ability to understand the meaning of things. I am talking about literacy *per se*, and when talking about scale we have 400 million illiterates in India. There is the question of equity, and I think that this a very important term that we ought to consider; and I have seen it across the whole spectrum, whether in the rural areas or the urban areas. And Professor Pinto DeMelo showed that in the case of Brazil the difference between the urban and rural is sectors very evident.

There is also a high degree of gender inequality; there is inequality between the young and the old. In fact Professor Cabibbo referred right at the outset to Professor Alberts and the fact that he had talked about those about the age of sixty. But I would like to say that if we just take the age group between fifteen and thirty-five, where the bulk of the working population comes from today in India, we have 110 million illiterates. There is also the problem of what are called 'drop-outs'. A 'drop-out' is essentially a child who joins school and does not proceed through school. He drops out at various stages in class two, in class three, and so on. And the figures for India are that for every 100 children who join class one, only twenty-five get to class 8. Seventy-five drop out. This is a very major problem.

And there is of course the state of schools, I think Professor Rao gave some indication of what the schools are like: roughly 40% of schools do not have blackboards; only 30% have libraries or laboratory facilities; and 73% have no proper buildings. Now, we heard a great deal about teachers, and I think Professor Mössbauer hit the nail on the head when he said that the most basic question is the teachers and the training of the teachers. But Professor Rao also told us about single-teacher schools. One teacher looks after the whole school, all the classes, all the subjects, and I can tell you that I have been to practically every part of India, because I have dealt with this field for eight years, with the planning of the education sector, and in a large number of these schools there is no teacher; there may be a single-teacher school but there is no teacher. Teachers who are appointed live in the better towns. They do not come to the rural areas. And you have schools in places where the children have to walk as far as twenty kilometres to go to school and come back, often across difficult territory, including mountains. With all this, quite clearly, there are going to be drop-outs.

There was also a discussion on the question of teachers not joining this profession for a variety of reasons. First, in most developing countries today you find that they do not have any real position in society, or respect for scholarship. We have discussed the question of the importance of money and the other professions available. Reference was made to how a good mathematics student goes on to do other things, maybe in financial areas, rather than becoming a mathematics teacher, and I know that a very large number of those who are actually teachers instead of teaching in their classes give take private tuition outside – that is where they make their money. They go for coaching classes, as they are called, to enable students to pass examinations.

What I really want to point out is that we are really dealing with a different animal, dealing with a different problem in terms of the types of issues that come up in terms of the scale involved, and therefore I really asked myself when this workshop was planned: how can science and technology percolate into the educational system? I want to see in what way we can use our current scientific and technical capabilities to overcome this problem of scale, of distance, of access, of timing, because very often the problem that arises in developing countries is that schools are far away, they operate on fixed timings, and these are not the timings when students can go to school. Therefore they do not go to school or when they have other things to do they drop out. Can we therefore overcome the barriers of distance, the barriers of fixed locations and school buildings and the resources required? Can we overcome the barriers of time? And this is why I want to talk about science education and information technology.

Many here are probably familiar with the fact that one of the successful programmes conducted in India is what is referred to as the 'green revolution', the increase in food production. At that time television was just coming on the scene, and perhaps the first programme ever conducted in India on television was what is referred to as 'creshi dashan'. 'Creshi' is agriculture, and dashan is a view; and this was essentially to put across on television what was important to farmers in terms of seed varieties, what to sow, pest control techniques, and so on and so forth. This was a process of real education which was of value to them in terms of what they were actually doing.

This still continues. Later on, and this was really conceived by the person who envisioned the Indian space programme, Vikram Sarabhai, we had an experiment which is referred to as the satellite instructional television experiment. This programme essentially borrowed a US satellite, a dual stationary satellite, the ATS 6, moved it overhead from America to overhead India, and used it for education. Televisions were put in remote villages and there were programmes of relevance to these communities, not necessarily teaching them at a primary or a secondary school, but aspects which were related to the totality of what was relevant to them, relating to water, relating to health, relating to education, relating to general knowledge and so on and so forth, so as to open their horizons. This was a very successful experiment.

But since then has television has grown tremendously in the country, and today television is no longer regarded in information technology as being a separate entity. One has what one calls convergence, which means the totality of all aspects of information storage, dissemination, communication, computing and so on. Today computers, broadcasting systems and telecommunication systems converge. There is an IT convergence, and the question that I would like to really raise here is the manner in which one can use this. Dr. DeMelo referred briefly to the use of Internet. But I would like to say that we are not only dealing with the computer, but also with television, with all types of systems for storage and for the dissemination of information. There are now a variety of things happening which would enable this to take place. Let me give you just one small example of how slum children make use of computers. In Delhi one of the companies involved with computers installed a computer in a slum area with just a hole in the wall, so that the children could have access to it, and it was switched on. They came and looked at this new object or toy, played around with it, they were pressing buttons and so on and so forth, and they saw all sorts of things happening on the screen. They were illiterate street children, but they all learnt and they knew far more about computers than adults who had followed the manuals in which you go step by step.

Television today is essentially used within a consumerist framework. It is used by the news media for a whole range of things. How much information has been transferred to society on a real time basis, whether the September 11 WTC event or what is happening in Afghanistan, what happened when man landed on the moon or what was happening in Yugoslavia or anywhere else for that matter, or when a goal is scored in a world cup! All of it in real time is available to huge numbers of people, and they absorb it. This is the power of the television. And yet, because of the fact that it has been completely handed over, in a certain sense, to what are called market forces, education and health are rather neglected. Certainly we make the maximum use of business, of industry, of whatever they can do in the matter, but the primary responsibility in this sector will be that of government and of society, and therefore whatever means is available must be made use of by the public sector, and by that I mean government and society.

I would like to mention another area of information technology very quickly, and that is the area of languages. Reference is made to a whole range of issues relating to languages and Dr. DeMelo talked about various developments in Brazil. But if I ask myself in what way could I use them, the answer is: zero, except for kits, because they would all be in Portuguese. Elsewhere it would be in Spanish, and so on and so forth.

We have to realize that there are three thousand languages spoken in the world. Thirty-eight of these are spoken by more than ten million people. There are twelve which are spoken by more than a hundred million people. Language is a matter of great importance as we move into the future, if we want to have anything that is international, and not only international but also national. When we talk of India, we have eighteen constitutional languages in India, ten scripts, and about fifty dialects. Children, when we talk of primary education, grow up in their language groups with a mother tongue.

If you look at the way the human brain reacts to this, all information is essentially a process learnt in that idiom, that form of idiom. And in fact all records are kept in that fashion too. I mean, if you look at any farming records you will find that many records are kept in the local language, in that script. As we move into the future we have got to accept that language diversity is a basic trait of cultural pluralism.

There are different cultural identities, and hence a diversity, and on this rest the various forms of expressing feeling and thinking. Now, certainly it is true, and reference was made to the fact earlier on, that we have Internet. A very large part of it is in developed countries. I am not going into the detailed numbers on that. A significant part of it is in English, but if you take this very continent in which we are, Europe today, and take the number of languages in Europe, would one want to go over to an Internet based entirely on English? Or should we do what Professor C.N.R. Rao said and allow the gap to widen? He referred to standing on the bank of a river, a widening flooding river. Or are we going to have some mechanism whereby we can move over from one language to another with ease?

And I would like to just spend five minutes in telling you that this is possible, not just in a machine translation from language A to language B, but in moving across from any language to any other language, and that is something with which I have been connected, and it is called 'universal network in language'. This was something which was developed by a team of two individuals who originally worked on machine translation at Fujitsu and who then were at the Institute for Advanced Studies in Tokyo, the UNU. I will not go into the history of the whole development but what does it amount to? It amounts to the fact that you can express yourself in the language you know, English, or French, or German, or Hindi, or Gujarati or Chinese, or Russian or Arabic, and in the script that you know. It is then put on a computer in the way you normally put it on, it goes into the server, and then what you have is an electronic language which picks up the totality of it, the words, the syntax. It has an enormous dictionary for the purpose and resides in the server, in machine language, in computer language. This is the process of UN conversion. You can pick it up in any other language anywhere else. If I today send a message from here in Italian, it can be picked up in Beijing, in Chinese, or in Moscow in Russian, in those scripts and in those languages.

Here is an opportunity to go across all the languages and to break the barriers that exist today. Now, I could go into greater details on this but I do not want to because of a shortage of time. But what I wanted to point out is: first one has the power of the television, and a television set, particularly with cable television, and now there are powerful new techniques which are coming in including overcoming the last mile problem through wireless and local loop, a variety of things which exist, which display in a form which is absolutely explicit and clear. I am not now arguing that this can substitute the teacher, I do not say that at all. What I am saying, however, is that it is a powerful adjunct. In addition to that, you are not then dependent only on doing everything within that language framework. You can cross over from one language to another.

This can be done for all purposes that we are concerned with at this level, which is primary and secondary education. I am not talking of technical education in great detail, there will be special domain areas: if you are going into neurosurgery, if you are going into high physics, if you are going into molecular biology, then of course you require a whole range of new dictionaries and words and so on and so forth. But, on the other hand, if one is talking of two aspects, and that is what I would like to focus on, which is in the original definition of the purpose of the Conference, namely how science and technology percolate into the educational system, and how one can move over experiences across the world, and how one can relate this as science communication, namely the whole question of science and public understanding, then I think this too can be used in a very powerful way.

I can make a few clear suggestions about what should be done in this area. There has to be an immediate technological effort and an effort relating to lower costs. Efforts being made particularly in Brazil, in India, for instance, are bringing us down to the level of a hundred dollar PC, and I will make the prediction that soon we will have instead of the actual complex boards things printed on paper. You do not require all the elaboration required for the type of usage at this level. One would require systems that operate mechanically with battery systems, not only electrical systems. You have already seen Dr. DeMelo's projection on the availability of electricity; the situation in Africa is much worse; in the remote areas of India it is also very bad. My second suggestion relates to the increase in the number of languages connected to the universal network in language, because the universal network in language is the computer electronic language. But the language groups are working today on all the languages, all the standard languages of the UN system, plus a very large number of traditional languages, Hindi, Thai, Japanese, etc. which are not part of the UN system.

There has to be a commitment to the public sector and government funding of education, and particularly science education. There is I think the opportunity, and this is what Professor C.N.R. Rao in some sense hinted at, that there could be a declaration from here, particularly with the backing of His Holiness, on the importance of education for development, for values. I have not gone into this whole area which is a completely different area in its own right, but education is not purely technical, education includes value systems, and this of course finally brings us to a knowledge-based society which can use that knowledge effectively.

And of course I hope that we will also have the possibility of international programmes whereby very low cost science experimentation can be transferred, so that it can be used in much broader areas than presently. Indian experiments do not have to be confined to India, Brazilian experiments do not have to be confined to Brazil, Mexican experiments do not have to be confined to Mexico. One should be able to spread them around and make much larger use of them, and an international programme to make this possible is certainly called for. But I do believe that the very first part of the purpose of this workshop, namely how science and technology can percolate into primary and secondary education, is very important. It can be done, and I am not pessimistic about it, but it must attack the most single key factor in it: if you are going to deal with the world, scale is important.

BUILDING A VISION OF INQUIRY-CENTERED LEARNING A WORKSHOP DEMONSTRATION

DOUGLAS M. LAPP

The National Science Resources Center (NSRC), a science education center operated jointly by the National Academy of Sciences and the Smithsonian Institution, has developed a series of workshops that can be used to demonstrate inquiry-centered science learning. These “jigsaw workshops” have been very effective, not only with teachers and educational leaders, but also with university scientists and corporate leaders, as a way of building a new vision of the benefits of teaching science by engaging learners in scientific inquiry.

At the meeting of the Pontifical Academy of Sciences Working Group on “The Challenges for Science: Education for the Twenty-First Century”, the members of the working group had an opportunity to participate in a jigsaw workshop on buoyancy developed by the NSRC. This workshop is based on learning activities drawn from the *Floating and Sinking* curriculum unit, which is a part of the NSRC’s *Science and Technology for Children* (STC) elementary science program.

Working in groups of three, the participants performed one of the following investigations, using the simple apparatus designed for the STC program.

(A) This group was given a set of sixteen objects, which included a fishing bobber, wooden bead, glass marble, lump of clay, nylon bolt, aluminum nut, and eight large and small cylinders made of wood, aluminum, acrylic, and polyethylene. They were asked to: (l) predict which objects would float and which would sink; (2) develop a statement that would describe the properties of the “floaters” and the “sinkers”; (3) test their predictions by placing the objects in a water tank; (4) record their results and compare these results with their predictions; and (5) identify the major concepts and skills that children might develop by engaging in these activities.

(B) This group was given an uncalibrated spring scale, a box of paper clips to use as weights, and a set of five objects which included a large fishing bobber, a small fishing bobber, an acrylic cube, a nylon bolt and nut, and a large metal washer. They were asked to: (1) without using the spring scale, develop a strategy to compare the weights of the five objects and to place them in order from lightest to heaviest; (2) use the paper clips as weights to calibrate the spring scale; (3) using the spring scale which they calibrated, weigh each object, and compare this with their earlier results; and (4) identify the major concepts and skills that children might develop by engaging in these activities.

(C) This group was given a tank of water, a calibrated spring scale, a hook with a small suction cup that could be attached to the bottom of the tank, a nylon string, and a set of three fishing bobbers of different sizes. They were asked to: (1) without using any measurement tools, roughly compare the weights and volumes of the three fishing bobbers; (2) investigate the buoyant force on each fishing bobber by pushing it under water; (3) use the spring scale to weigh each of the bobbers; (4) using the spring scale, the hook attached to the suction cup, and the string, measure the buoyant force exerted by each of the fishing bobbers; (5) discuss their observations in order to draft a statement about the effect that volume has on the buoyant force; and (6) identify the major concepts and skills that children might develop by engaging in these activities.

(D) This group was given a tank of water, a lump of clay, and a bag of marbles. They were asked to: (1) discuss together a strategy that might be used to modify the shape of the clay, without changing the amount of clay, so that it will float with a cargo of 25 marbles; (2) test and modify this design until the clay boat floats with the 25 marbles; (3) design and construct a boat that will float carrying as many marbles as possible; (4) discuss the variables that affected the performance of their boat designs, including the effect of changing the volume of the boat; (5) identify the major concepts and skills that children might develop by engaging in these activities.

(E) This group was given a tank of fresh water, a calibrated spring scale, and a set of objects that included a metal cylinder, wooden cylinder, polyethylene cylinder, acrylic cylinder, black plastic cylinder, and a hollow cylindrical plastic container (all of the same diameter and volume). They were asked to: (1) predict which objects would sink and which ones would float in fresh water; (2) test their predictions by placing each cylinder into the tank of fresh water; (3) use the spring scale to weigh each cylinder and record these weights; (4) fill the hollow plastic container with water, record its weight, and compare this weight with the weight of the other cylinders; (5) develop a statement that describes the relationship between the weight of each of the cylinders, the weight of the container of fresh water, and each cylinder's tendency to float; (6) identify the major concepts and skills children might develop by engaging in this learning experience.

(F) This group was given a tank of salt water, a calibrated spring scale, and a set of objects that included a metal cylinder, wooden cylinder, polyethylene cylinder, acrylic cylinder, black plastic cylinder, and a hollow cylindrical plastic container (all of the same diameter and volume). They were asked to: (1) predict which objects would sink and which ones would float in *salt* water; (2) test their predictions by placing each cylinder into the tank of salt water; (3) use the spring scale to weigh each cylinder and record these weights; (4) fill the hollow plastic container with salt water, record its weight, and compare this weight with the weight of the other cylinders; (5) develop a statement that describes the relationship between the weight of each of the cylinders, the weight of the container of salt water, and each cylinder's tendency to float; (6) identify the major concepts and skills children might develop by engaging in this learning experience.

After engaging in these activities, the participants discussed the "Focus-Explore-Reflect-Apply" learning sequence that is utilized in the STC science learning materials. The participants also discussed the special benefits that result from engaging children in inquiry-centered science learning as demonstrated in the *Floating and Sinking* demonstration workshop.

EXAMPLES OF SPECIFIC APPROACHES/SUCCESSES IN VARIOUS COUNTRIES

THE PROBLEMS AND PROMISES OF SCIENCE EDUCATION IN CHILE

JORGE E. ALLENDE

Chile is in a process of developing its science and technology capacity. Having worked as an active scientist for 40 years in my country and having lived through very difficult times, I am optimistic that now we are making some significant progress.

I will show you a few facts why I am optimistic.

Transparency 1 shows the number of scientific publications indexed by the ISI originating in Chile through the last decade. Presently there are more than 2000 publications per year. Per capita this is the highest number of publications for any Latin American country.

The number of publications is important, but the quality and impact is more important. The following transparency (2) shows the number of citations per publications and the ranking of the different countries with this criterion. We see that Chile occupies the 23rd position – the highest for any developing country and ahead of some European countries with long traditions of research such as Greece and Poland.

In transparency (3) I have included some new Programs for support of science in Chile which have been generated by the government and which

Transparency 1. ISI PUBLICATIONS FROM CHILE

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
SCI SEARCH	1.220	1.197	1.306	1.404	1.412	1.629	1.739	1.770	1.843
% World Total	0.178%	0.170%	0.181%	0.184%	0.177%	0.190%	0.193%	0.189%	0.195%

Transparency 2. THE 30 CLASSIFIED NATIONS BY CITATIONS PER PUBLICATION (1992-1996)

Country		Citations by Publication	Number of publications	Total citations
1	Switzerland	5,66	55.213	312.564
2	United States	5,03	1.239.188	66.234.187
3	Netherlands	4,45	80.016	356.025
4	Sweden	4,38	61.072	267.685
5	Denmark	4,38	30.719	134.616
6	United Kingdom	4,19	330.677	1.259.427
7	Belgium	3,94	38.095	150.206
8	Finland	3,93	26.998	106.151
9	Canada	3,83	167.326	641.114
10	Germany	3,78	258.956	979.823
11	France	3,66	197.816	723.156
12	Austria	3,54	24.388	86.275
13	Israel	3,45	39.977	137.980
14	Italy	3,42	116.534	398.285
15	Norway	3.30	19.814	65.305
16	Australia	3,23	85.215	275.599
17	Japan	3,18	280.855	892.029
18	New Zealand	2,94	17.015	59.007
19	Ireland	2,78	9.233	25.630
20	Spain	2,72	73.224	199.443
21	Hungary	2,55	14.768	37.724
22	Portugal	2.40	7.135	17.097
23	Chile	2,31	6.666	15.366
24	Greece	2,02	15.216	30.666
25	Poland	2.00	32.728	65.610
26	Argentina	1,98	12.266	24.334
27	South Africa	1,94	17.418	33.737
28	Hong Kong	1,92	19.379	40.106
29	Mexico	1,91	13.043	24.962
30	Brazil	1,89	25.578	48.406

Source: ISI – Science National Indicators

Transparency 3. NEW PROGRAMS FOR SUPPORT OF SCIENCE AND TECHNOLOGY IN CHILE

FONDAP PROJECTS CONICYT *1999, 2001*	7 projects in Astronomy, Oceanography, Physics and new materials, Applied Mathematics, Cell Biology, Signal Transduction and Ecology 1 million USD/year for 10 years
MILLENIUM INSTITUTES WORLD BANK – MINISTRY of PLANING *1999, 2001*	3 in Biophysics, Biotechnology and Genomics 700.000 USD/year for 5 years 10 Nuclei 300.000 USD/year for 3 years
INTERAMERICAN BANK – MINISTRY of ECONOMICS *2000-2005*	100 million USD for Technology Development in Informatics, Biotechnology, Agriculture (5 million for Genomics)
WORLD BANK – MINISTRY of EDUCATION *1999-2002*	250 USD million for higher education From this, approx. 50 USD million are dedicated to support Doctoral training and expensive research equipment

are improving the situation for funding for science and technology research in our country.

President Lagos is truly interested in scientific research and understands the relevance of science for cultural and socioeconomic development. We must recognize that despite the present financial crisis which has hit our country very hard, he is trying to honor his promise to double investment in R&D from 0.6% of the internal product to 1.2% during his 6 year term.

This may sound very rosy to you, but despite our optimism, we recognize that we still have very big problems. The biggest of them is that our society in general is not aware of the importance of endogenous science for their own development and for the progress of Chile as a nation. For most people in Chile, Science is something magical, complex and expensive that is done in the United States, Japan and Europe and that results in new gadgets or medicines that eventually appear in the stores, supermarkets or pharmacies in Santiago. The general public does not realize that scientific research and knowledge generation is something that can and should be done in their own countries and that their future and especially the future of their children depends on this.

Unless the perception is definitely changed and a general consensus among our national and regional (Latin American) societies is achieved, our present rosy picture will be fragile and ephemeral and will be changed depending on whether we are lucky on the political lottery and draw a more or less enlightened President or Minister.

It is obvious that the most sure and efficient way of changing the situation and achieving a society that understands and values science is through science education of our children.

But our argument must not be the selfish one of improving science education because that way we will get more money for science, for our labs and for our students. We should emphasize that science education must be improved because the knowledge, the attitudes and the values of science are essential for our children to live a fuller, freer, more democratic existence in the 21st Century.

Unfortunately the level of science education in Chile is very low. This statement is objectively ascertained by international tests as well as by national measurements. Rafael Vicuña presents in his contribution the results of the TIMS international test in which Chile is very close to the bottom of the list. The same very negative results can be seen in the SIMCE, a national exam that also tests natural sciences. (Transparency 4).

The most disturbing factor of these test results is the great disparity between public education, attended by the poor and the lower middle class (70-75% of the people) as compared to the private education of the privileged part of society. This is disturbing because it indicates clearly that we are not providing an equal opportunity to the children of the poor, on the contrary, we are giving them a handicap in the competition to enter the University or to prepare themselves for their life work.

Transparency 4. RESULTS OF SIMCE NATIONAL EXAM IN NATURAL SCIENCES

4º Year of Primary Education – % correct answers

Year	Municipal Public	Private State Supported	Private Paid
1992	56.1	62.5	76.3
1994	64.3	67.4	78.0
1996	65.7	69.0	81.4

Average of 24.000 students in a National sample

8º Year of Primary Education – % correct answers

Year	Municipal Public	Private State Supported	Private Paid
1991	47.81	52.32	67.11
1993	50.87	55.03	68.33
1995	55.68	60.15	75.14
1997	59.26	63.05	75.42

The last two years around 150.000 students were tested

The key factor to explain this low level resides in the training and support received by those rather heroic individuals that teach science at the primary and secondary education.

The market economy and the low salaries and poor social recognition that teachers receive in our countries have made teaching in pre-university

Transparency 5. SECONDARY SCHOOL SCIENCE TEACHERS GRADUATING IN CHILE – 1999

Mathematics	78	[*only 7 graduated from a research University*]
Mathematics and Physics	4	
Physics	11	
Chemistry	37	
Chemistry and Biology	4	
Biology	44	
Total	178	

In the national entrance exams, the students accepted to train as science teachers were in the lowest 30% of those accepted to institutions of higher education.

education very unappealing. Despite incentives and fellowships recently provided for those that enroll in teaching careers in Education Faculties and Teacher Universities, the numbers of those graduating in science teaching are terribly low. (Transparency 5).

In addition to the low numbers, their performance in the national university entrance exam shows that the students applying to be the future science teachers have some of the lowest qualifications of any profession.

To compound matters, only a very small percentage of teachers graduate from the few research universities that we have in the country. Therefore, science teachers graduate without ever being exposed to the real active science and without having contact with working scientists.

Obviously this rather dismal picture has to be changed drastically if we are to improve science education.

We have to raise the salaries and prestige of teachers and have to get the research universities involved in teacher training. Those are national policies that imply major financial and political decisions.

Another area in which scientists and scientific institutions can and should directly participate is the area of working with science teachers and with the education institutions to update their knowledge of science progress and to provide them with materials and tools that can be used to transmit to the children the fascination and the adventure of science.

As will be stressed in a special session of this meeting, we, the scientists individually and collectively have a responsibility to work to improve the science education that is provided to our children and youth.

This responsibility arises from our contract with society, with our duty to inform society what we are doing and why our work is important for our countries and the world. We have to serve as antennae for our people to tell them what is happening in the world of knowledge and how new scientific discoveries impact them. We also have a responsibility to prepare the children and the young to grasp the opportunities of the Age of Knowledge.

I am pleased to report that in Chile the scientific community has become aware of this responsibility and has started to do something about it. (Transparency 6).

The Chilean Academy of Sciences and the scientific societies gathered around the National ICSU Committee have played a key role in organizing the National Association of Science Teachers, which now has close to 1000 members throughout the country. This association founded in 1994 as a result of an interacademy meeting held in Santiago in 1993 organizes a yearly Congress and stimulates many activities. Its headquarters are precisely in the premises of the Chilean Academy of Sciences and since its foundation it has been a joint effort in which scientists collaborate with science teachers in those areas in which they require support.

The Chilean Academy as a result of the meeting of the Interacademy Panel held in Tokyo last year, also decided to increase its concern with science education. We are organizing a meeting in January 2002 to which 15 other academies, from other Latin American country and from may other countries will participate.

The focus of this meeting is the design and use of simple experimental materials in the classroom to allow children to use their hands and do experiments and learn on their own important scientific principles. We have obtained support from the Andes Foundation and the Minister of Education to organize this meeting. More important than this, is the fact that both a group of scientists and the Ministry of Education are excited to start this kind of Program in our country.

Another very positive aspect is that the Ministry of Education is very much aware of the need to raise the level and equity of education in all areas but very specifically in the sciences.

Transparency 6. INVOLVEMENT OF SCIENTISTS IN SCIENCE EDUCATION ACTIVITIES

1) *Chilean Academy of Science and National ICSU Committee*
   - Foundation of the National Association of Science Teachers in 1994.
   - Organization of an International Meeting of Academies to discuss the use of experimental materials in inquiry based learning of science Santiago, January 9-11, 2002

2) *Ministry of Education*
   - Educational Reform together with a group of active scientists have defined a set of Fundamental Objectives and Minimum Obligatory Contents for Primary and Secondary Education
   - Detailed programs for each discipline for each year of basic and secondary schools
   - Massive training courses for teachers
     These programs provide examples of content and activities for teachers and "Benchmarks" for student attainment.

3) *The National Research Council (CONICYT) - EXPLORA Program*
   - has the objective of making science accessible to society and stimulating science education.
   - National Science Week (every year)
     1000 scientists in 1000 class rooms
   - Science interactive museum

4) *Research Universities*
   The Instituto de Ciencias Biomédicas, Faculty of Medicine, University of Chile
   - Teacher training courses in biology
   - Practical course on molecular biology
   - Adoption of schools in poor neighborhoods
   - Training of bright students to enable them to enter University careers

To achieve this, a very large and ambitious Educational Reform Program has been launched by the Ministry of Education a few years ago and in the framework of a large increment in the investment in education.

In the area of sciences, the Educational Reform as designed by the Ministry of Education has worked with a group of very active scientists to define a set of Fundamental Objectives and Minimum Obligatory Contents of Secondary Education. The publication of a book with these essential definitions has been a very important step which require an active debate, which in the case of Chile, was concluded with the decision to maintain the rather conservative idea of the large scientific disciplines, not the more revolutionary idea of integral learning of all sciences.

The group of scientists and educators in the Ministry has gone on further to provide Programs of content and activities for the teachers as examples of what they should be doing with their students to achieve the minimal standards. These Programs are books for each subject and each year of basic and secondary education and serve as teacher's guide and also as a guide for the authors of text books which are selected in an open competition. These Program books are extremely helpful to point at "benchmarks" of knowledge that the students should attain in these subjects.

I think this is a very positive example of how government policies can be implemented with the very active and decisive help of active scientists who are generous enough to give their time for this crucial task.

Another very important activity that is being carried out by our government with the help of the scientists is the Explora Program of the National Research Council (CONICYT). During the past 3 or 4 years this Program has greatly increased its activities of motivating children and science teachers to undertake projects and initiatives in science education. EXPLORA organizes a yearly science week that take place in our Spring. In that week there are many activities but the most important is called "1000 scientists in 1000 classrooms" in which that number of scientists visit and give lectures to primary and secondary school children about science, its fascination and its impact. Although this is a large part of the Chilean scientific community, there is no problem getting the scientists to agree to give these lectures because they find it a very rewarding experience.

A new interactive science museum build in Santiago is also a very positive aspect in this area.

A further example of what is being done by scientists in the area of education deals with University units.

I have stated that one of the most serious problems with teacher's training is that this is carried out in Education Faculties or even in "Teacher's Colleges" or Universities. These Faculties or Universities do not have groups doing scientific research. It can be concluded that science teachers are trying to convey to their students about the marvelous achievements of science without ever visiting a laboratory or talking to active scientists. This situation is made more serious by the celerity of scientific progress. It is very difficult for the scientists themselves to keep up with the advancement of the ideas and techniques in their specific field, obviously it has to be impossible for teachers to maintain abreast of a very wide discipline of knowledge about which news are coming out every day in the internet and in the news programs.

We can and should do something to remedy both situations. Scientific institutes and university departments that are research oriented should take part in organizing training courses for updating teachers.

In our Institute of Biomedical Sciences, Faculty of Medicine, University of Chile, we are actively working with biology teachers in the public schools of Santiago running courses on morphology, physiology, genetics and molecular biology.

In this last subject we have developed a practical one week course in which we have trained more than one hundred high school teachers. It is great to see the excitement of these teachers when they can clone genes and transform bacteria and isolate DNA.

We have the project of developing a mobile DNA laboratory that can visit schools and let the students carry out experiments of genetic engineering.

One of the most worthwhile programs undertaken by the Faculty of Medicine deals with the adoption of 3 high schools of one of the poorest neighborhood in Santiago, called La Pintana. This means that the teachers of those schools get the chance of a number of special training programs to help them raise the level of their teaching. In addition, 8 of the top students from that neighborhood are receiving special individual tutoring in the Faculty of Medicine with the objective to get them to do very well in the national entrance exam so that some of them can enter medical school or some other university careers. That was something unheard of in that neighborhood of La Pintana, its youth thought they had no future and were destined to increase the number of jobless or problem citizens. The fact that some of their own will be given a chance to escape this fate has had a tremendous impact in the morale of the whole school system of this poor municipality. It is something we should expand.

We are pleased because in the past few years, our scientific community has really started to understand its responsibility and has worked with enthusiasm on science education. However, it is a huge, massive task and there is a great deal to be done.

In this respect, I think that it is very important in this international meeting that we go further than the stimulating exercise of learning from each other what we are presently doing. In my opinion there is a need for generating international collaborative projects in this area in which we can synergize and complement each other and make full use of the resources and infrastructure available in various countries.

There has been a lot of discussions about the good and bad things of globalization. Well, whether we like it or not, science is a globalized area that was born that way, there is no folklore in science, international science is the only true science. We should make use of this in science education through international efforts.

Transparency 7. PROPOSALS

Academies and scientific institutions should generate one or many projects to carry out joint international activities dealing with pre-university science education.

1) International courses to train and update science teachers

2) A set of "benchmarks" of minimal required objectives for the attainment of children at an international level

3) Sets of experiments and materials that could be available to science teachers of any country

4) International science teacher prizes

These activities should be included in an international project.

For instance (transparency 7), we could organize international courses for updating science teachers. We could generate and agree on an international set of benchmarks for our children's science attainments. We could design sets of experiments and materials that could be available at minimum cost in all countries. We could institute international science teacher prizes for outstanding achievement. I am sure that you will have many other ideas, but it is certain that if academies with the prestige of the Pontifical Academy, together with TWAS and some of the National Academies, get behind such a project, we will be able to find funds to support this very worthwhile effort.

CLOSING THE EDUCATIONAL GAP AMONG TEENAGERS

ANNA S. KASHINA

Introduction

This paper focuses on science-specialized high schools – a highly successful educational experiment, initiated and carried out by Russian scientists, ranging from top-level scientists, including the famous mathematicians I.M. Gelfand and A. Kolmogorov, to graduate and undergraduate students. Such specialized high schools have been organized on the base of average schools with enhanced studies of one or several scientific subjects. In the rigorous educational system of the former Soviet Union they co-existed with a large amount of regular schools and foreign language schools.

The extreme success of this experiment, both in bringing up younger generations of top level scientists and professionals, and in increasing the general level of education, led to the development of a widespread system of schools in the scientific centers of Russia, such as Moscow, St.Petersburg, and Novosibirsk that succeeded the Soviet times in Russia and is flourishing up to this day. The first school was initiated in 1958 (Moscow School #2), the next few were started in 1968 (including the famous Moscow School #57). Currently there are over 30 specialized schools in Moscow alone.

While this experiment remains an example of an educational success, rather than a panacea for the educational problems in the world, a similar approach can make a valuable contribution to education in any country by creating a core of intellectuals that can serve as a foundation of the scientific community of educators. This core can be instrumental in setting up standards, principles, and traditions in general education and eventually in becoming leaders in the educational development of students, teachers, and parents, with whom the education really starts.

Principles and tools

Education in specialized high schools was based on four basic principles. First, it integrated learning with cultural and moral development, teaching, besides the scientific disciplines, a system of values that provided the necessary foundation for learning science. Second, it created an atmosphere of 'learning as an adventure', where the teachers assumed the roles of leaders and mentors, rather than simply delivering the information. Third, it made no distinction between students from different socio-economic background. And fourth, it allowed each student to study at their own individual pace, without distinction between the initial performance of different students. Each of these principles is described in more detail below.

Specialized schools used a common set of tools. The first and most important tool was the core of highly enthusiastic university teachers, aided by graduate and undergraduate students. All of them in Russian specialized schools did this work voluntarily, without being paid. Second tool was the educational methods that involved, besides classes, a number of extracurricular activities, designed to create an atmosphere that encouraged students to learn. One of the most important extracurricular activities included educational field trips that, besides teaching, created an atmosphere of companionship, and bonding between students and teachers, and, as a result, turned learning into a collective game. Finally, the specialized schools used as their basic tool regular, average high schools, in no way special by any other criteria.

Here is how the specialized education fit into the regular educational system. All the high schools in Russia had 5 days a week (6 hours a day) of classes taught by a unified nationwide school program, and 1 day a week of vocational education, designed to give students some direction towards a simple profession, for example, a driver, or a seamstress. In specialized schools the basic program was the same, but the vocational education was replaced by the equivalent amount of hours a week (i.e., 6-8) of specialized classes, such as biology, mathematics, or chemistry. In addition there was a slightly heavier load of hours and extracurricular activities, such as field trips and cultural events. This specialized program was entirely up to the organizers in each school and thus it differed a lot between different schools. Therefore the specialized schools fitted naturally into the general education system, but added very important extra elements to it.

Selection process and curriculum

Selection into specialized classes took place in April-May for the upcoming academic year. It was directed at selecting students that were interested in the subject, were able to think independently, and were motivated to learn more. The grades attained in the previous schools were not a part of consideration, and the previous level of education was also generally considered unimportant. Specialized schools aimed at finding students willing to learn and compatible with their educational methods, not merely the top graded students.

For example, selection process into the biology classes at Moscow School #57 – one of the core specialized schools in Moscow – consisted of three rounds. The first round was a written test on subjects of general science within the school curriculum, which selected approximately 100 students out of the general group of applicants. At the second round the students underwent three one-on-one interviews with the members of the organizing groups. These interviews were usually conducted not by main class organizers, but by the university students helping them out, mostly the recent graduates of the same classes. They were aiming to determine the students' thinking abilities and compatibility with the program and therefore didn't restrict their questions to biology or even science (for example they could ask what is an applicant's favorite poem and why). This selected around 30-40 students for the final round. At the third round all the finalists had a 10-minute interview with the main organizer(s) of the class. These interviews, conducted in a format similar to the second round, selected anywhere between 15 and 20 students for the class.

An important addition broadened the implications of this educational experiment. 8-10 students from the neighborhood, for whom that was the closest school, were accepted into specialized classes without such selection, first-come, first-served, based on their willingness to join the class. This was done as an attempt of the program organizers to determine how applicable was their educational system to all students. As a result the specialized classes were very diverse, consisting both of top students from highly educated families all over Moscow, and of students below, often – much below average from common families in the neighborhood.

Contrary to expectations, having these two groups together in the same class didn't produce any problems or conflicts, because the general spirit, created by the teachers, was that of a participation in a special experiment, of blending together instead of emphasizing the differences between the students' socioeconomic or educational backgrounds. In addition to the spirit of enthusiasm and adventure, the rules were backed up by iron discipline, enforced by the peers through often unspoken disapproval.

Table 1 gives an example of specialized classes taught to the biology students in the Moscow School #57.

Table 1. CLASSES AND EXTRACURRICULAR ACTIVITIES IN THE SPECIALIZED BIOLOGICAL EDUCATIONAL PROGRAM (TWO LAST YEARS OF HIGH SCHOOL, 9TH AND 10TH GRADE, 15 AND 16 YEARS OF AGE, RESPECTIVELY).

Regular classes taught by enhanced program:

Mathematics	6 hrs/week of algebra and geometry
Physics	3 hrs/week
Chemistry	2 hrs/week
Russian and Literature	4 hrs/week
Biology	1 hr/week

Specialized biology classes, not taught in regular schools:

9th grade:

Zoology of Marine Invertebrates	1 hr/week lectures, simplified university program 1 hr/week practical course
Biology of Higher plants	1 hr/week, special course
Entomology	1 hr/week, special course
Cell Biology	1 hr/ week lectures, simplified university program 1 hr/week practical course
Ecology	1 hr/week lectures

2nd year (10th grade):

Genetics	2 hr/week full university course
Human Anatomy	1hr/week full university course
Cell Biology	2 hrs/ week full university course
Vertebrate Zoology	1 hr/week, special course

Extracurricular activities:	1-day field trips	1 Sunday/month
	1-week field trips	2-3 times/year, quarter breaks
	2-month field trip	between 9th and 10th grade
	Cultural events	once a month

In specialized schools some of the regular school subjects were taught by enhanced program. For example, biology students had, in addition to biology, enhanced mathematics, physics, and chemistry. All students had extra activities at other classes, such as literature, where they took time during the class to read and discuss their favorite poetry. On occasion the teachers even managed to include into classes the discussion of the Bible, which was very hard to do in the Soviet times, but in the teachers' opinion necessary to develop the moral values of the students.

The specialized biology classes were taught by volunteer university professors and students. During the first year heavy emphasis was placed on the 'old-style' biology, such as zoology and botany that was regarded as a necessary foundation for the future knowledge of more 'modern' subjects of biology. In the second year the emphasis was shifted to the 'modern' biology, with the curriculum for many subjects actually the same as taught to the first year University students (underlined in Table 1).

Teaching methods: individual pace for each student

A very important reason this education proved so effective was the following. In class teachers gave students the materials and allowed each of them to work at their own pace. At the same time, they were encouraged to ask questions, even if these questions concerned the program of previous classes, which the students were supposed to know.

The rationale, as given to the students, was that questions help not only the student but the teacher, and that the people who don't have questions can never learn anything. The teachers encouraged questions by pointing out that they themselves don't know everything and may very well make a mistake or not know the answer. To make it easier in some classes, along with the 'main' teacher several 'junior' teachers were present, who helped answer questions or refer them to the 'main' teacher if necessary.

As a result, an interesting thing came up. It turned out that most of the chronic non-performers, who used to have bad grades and were labeled as incapable of learning, in reality simply missed some previous parts of curriculum, and as a result lost hope to ever catch up. When they were allowed and encouraged to start from the previous parts of program, - 3 years behind, if necessary, - and ask any questions at all, they started to catch up very quickly, first doing problems at a much lower pace than others, but eventually becoming as good as the rest of the class, or, in some cases, better.

Other students had opposite problem – they finished their task much too quickly and were bored. Those students were always given an option to leave or to study more if they wanted. In the atmosphere of 'learning as a game' most of them chose to stay and keep studying. As a result those students who had a naturally slower pace of work didn't feel discouraged, and those who had a faster pace didn't feel bored.

An important conclusion from this is that *regular school education is directed at a non-existent 'average' student*: material is given at an average pace that is too fast for some students and too slow for others. As a result in regular schools some students are habitually bored and might eventually be turned off by the education process in general, and others never have a chance to develop their abilities. The education methods in the specialized classes dealt with this problem in a very efficient way. Even the original non-performers eventually became comparable with the top students in other schools.

Moral values and atmosphere

What was, in the end, so special about the specialized education? Definitely not the extra classes and extra material *per se*: such things are known in many educational systems and by itself they never have produced such striking results. It was not even the extracurricular activities by themselves, and not the unusual teaching methods. It was the combination of all these things and more: the atmosphere, created by enthusiastic teachers who wanted to apply their best effort to bring up a generation of students like them.

In a way these teachers approached the education as they approach the task of bringing up their own children, developing them morally as well as mentally, creating a group of people they themselves would enjoy being with. In such atmosphere the education came naturally, not so much as the result of lessons, but of this continuous interaction, where the most important thing was to come up with the true answer to each question, and searching for these answers in itself was what bonded the students together. This atmosphere bred intellectual hunger that was not confined to the specialized subjects. Students from these classes took turns to stand in line overnight for the tickets to the best art exhibits and plays; on one occasion a large group of students stayed behind after the literature class and spent four hours arguing whether Tolstoy had meant his Count Andrei to be a positive or a negative character.

What these students actually had in school was, on top of education, a life full of fun, companionship, and intellectual challenge, which taught them all the moral values, both in scientific research and in life in general. Many came to the school in search of this companionship, undergoing the tough selection process and often having to travel more than an hour each way to study there.

It is known that roughly around the time of high school teenagers start growing out of their family bonds and looking for a group of people to belong to. In some modern societies they often find only gangs, or rock groups, or extremists groups; or they find nothing at all and then become lonely and depressed. It seems feasible to attempt at providing alternatives for students, such as specialized schools that can give them a chance to belong to a wonderful group of people. It can give the teenagers a lot more, as taught by the example of the Russian specialized schools.

Above all these schools give students a head start, not only for professional science, but for other pursuits as well. Graduates of these schools are now working all over the world, and a few of those are leading scientists in their fields. Some of them have become engineers and doctors, artists and writers, or even military commandos. Several people chose to organize their own specialized classes at other Moscow schools.

Even more than that, such education gives students a broader and keener understanding of life and people, which really makes every aspect of human interaction a much better experience. And finally, for better or worse, it gives them independence of thought in a good sense, a quality – so necessary in a scientist – of questioning everything and arriving at their own conclusions, which in the end is making their convictions and sense of righteousness a much firmer foundation.

Implementations within other educational systems

The tools used by specialized schools exist in virtually any society and can be implemented within almost any educational system. Average schools – the foundation for specialized education described here – exist everywhere. There are certainly many ways to introduce additional classes into a regular school system. Many of those exist already, such as Sunday schools and honor classes. Similarly, there exist field trips for school students, such as scout trips and summer camps. Finally there are University Outreach programs, where scientists give lectures to high school students.

The new element, and the most important limitation of implementing the experience of Russian specialized high schools in any society, are enthusiastic volunteer teachers who would be willing to approach education with the same energy and responsibility as if they are teaching their own children.

Such people exist in any society, but are hard to find on a large scale. Perhaps they should be looked for initially not among the school teachers, but among the scientists, who are willing to bring their knowledge to schools. Tremendously important would be an effort to increase public awareness of science in general and science education in particular, since only then the students, the teachers, and even more importantly – the parents become aware of the necessity to learn science as a part of intellectual and moral development of a healthy individual, as well as a part of survival in the modern world.

While the example of the Russian specialized schools cannot be viewed as a total reform of educational system, but rather a useful addition to it, such an effort seems to be really worthwhile, since the results of such education have extended beyond just mastering the curriculum to the intellectual awakening and change in the value system.

SCIENCE EDUCATION IN FRANCE: ‘*LA MAIN À LA PÂTE*’

PIERRE J. LÉNA

1. *Education in science, a new concept?*

In France, the issue of the scientific litteracy of the society is most often raised in terms of *culture scientifique et technique*. Several studies have recently been published, showing the coexistence, in the public opinion, of a high degree of interest for science and technology, associated with a great ignorance and many fears. Within the scientific community, there is a lasting consensus that this situation is not satisfactory and requires specific actions. In the last two decades indeed, numerous efforts have been made by the public authorities, the research institutions, the science community through its professional associations in order to bridge this gap and amplify the transfer of scientific results to the public.

Some of these efforts aim to improve the information of the public through the media (press, television), others to stimulate the creation of centers (*Centres de Culture scientifique et technique*) which mediate the knowledge towards a large public on a local basis, others to open the scientific or industrial laboratories to the public in a yearly national *Science Week* which has now twenty years of existence. Most scientific research institutions (CNRS, INSERM...) have developed in-house special offices dedicated to communication, with the aim to make known their activity to the press and the general public. The emergence of science and technology into society debates (genomics, procreation, climate, etc.) now leads to new forms of exchanges, which go beyond a pure scientific information: *cafés scientifiques, conférences de citoyens* (citizens debates), Internet forums, which are reflected in the press.

While this *information on science* (and technologies) tries to cope with the pace of discoveries, their impact on society and the political debates they imply, another aspect began to emerge in the last decade, namely *education in science*. This is clearly an issue for the school system, which in France is strongly centralized, and deals with curriculum choices, teachers training, recruitment and evaluation. What should be the goals of a proper education in science, to be given to everyone during the school years, especially during the compulsory education, which in France lasts until the age of 16 and is in principle identical for everyone? does the change in the volume, the rapidity of development and the impact on society of science and technology force to reconsider the way science is taught in schools?

Education in science can be understood as the goal to share methods, history, values and results of the scientific and technological development. It is not to be conceived as a mere accumulation of facts, results, 'scoops' on discoveries, fragmentary knowledge, formulas or practical rules. It is a subtle access to this apparently miraculous ability of human intelligence, brain and hands together, senses and measuring artefacts together, to unveil the mysteries of nature and to become able to act on it, predict the future and develop new artefacts, in a cumulative process of development, specialization and cross-fertilization of disciplins. Achieving this *education* requires pedagogy, continuity, appropriate tools and methods, the partnership of a teacher and can not be confounded with *information*, which is needed but today appears as a volatile and often superficial product of the consumerist society. The ambition of education is to introduce everyone to this mixture of pure imagination and inflexible rationality leading to the scientific knowledge and subsequently to a power upon the natural world.

The transformation of the pace in science and technology evolution forces to reconsider entirely the ways through which the school system handles this challenge. The scientific community, the role of which has been essential in the development *of information on science* in the last two or three decades, as briefly discussed above, has to become involved also in this new issue, to a degree it ignored up to now. On top of its traditional *raison d'être* to create new knowledge and to disseminate it to the new generation to ensure a cumulative development, it bears a new responsability of *knowledge sharing*, which implies a more direct role and impact on the education system, and especially on teachers.

The central role of teachers for a good education in science is obvious. Yet, the community of science teachers (in *collège* and *lycée*), in the last two or three decades in France, became more and more separated from the mainstream of science and technology, became cut from active research and even organized in professional associations which have little or no relation with active scientists. One key issue is therefore to reinstall a kind of common interest and understanding between the two communities. An adequate place for this should be the pre-service and in-service training of teachers, since there is no hope for the science to remain the same during the several decades of duty a teacher will have.

2. *Evolutions in France*

It was progressively realized, by the mid-90s, that science was essentially absent from primary school education in France, as this education was instructed to focus on the so-called *fundamentals* requirements of reading, writing and counting. A movement called *La main à la pâte* was started in 1996 by Georges Charpak, Nobel Prize in Physics 1992, with the determinate support of the Académie des sciences, aiming at a rejuvenation of science teaching for children of ages 5 to 12. This movement is briefly described in the Appendix and its positive lessons are discussed below.

The lessons from *La main à la pâte* action and the worrisome recent decrease of science students in higher education leads now to a new question, i.e. the validity of the science/technology teaching achievements in the *collège*, namely the four years (12 to 16 in age) which end the compulsory school time in France. Since 1974, this *collège unique* is conceived on a uniform scheme for all pupils, no matter what their achievements, background and professional wishes or plans are. Although this formula has the merit to refuse former disparities, related to social classes, and to propose an equalitarian and uniform frame of learning for all children, it is more and more questionned in view of the problems encountered in classes.

The *collège* is today, certainly, the most difficult part of the French education system: teen-agers are in a difficult period of their personal development, teachers are submitted to strong but often contradictory pressures from the society and the parents, violence has irrupted in many classes, social integration of minorities is difficult. Science teaching is broken and parcellized in three independent disciplines (physics & chemistry, life & earth sciences, technology) which barely lead to a clear understanding of the nature of scientific knowledge and their role in society, not to speak of the relation of science with other disciplins such as language or history. Put in perspective with Gaston Bachelard's words '*For a scientific mind, every knowledge is an answer to a question. Nothing is obvious. Nothing is given. Everything is built up*', our science teaching gives answers long before the teen-agers are driven to ask questions!

Nevertheless mathematics teaching, a traditional strong point in French schools, remains good, possibly for unsatisfactory reasons: proficiency in mathematics continues to be considered, by the parents but also by the system, as a *sesame* for almost any career.

After the *collège unique*, while a small fraction of each generation goes directly to work or keep some kind of apprenticeship, a larger and larger proportion (78% in 1999) continues the school, eventually reaching the *baccalauréat* or going beyond. In these three years which terminate the secondary cycle, for six students, three go to the *lycée général*, two to the *lycée technologique* and one to *the lycée professionnel*. Of the whole system, these three years are probably the ones where science/technology teaching is the best, where transformations are relatively easy and require relatively less attention.

Another concern recently emerged from the other extremity of the education system, namely from Universities and Engineering schools (Grandes Ecoles). From 1995 to 2001, although the number of students selecting sciences or science related technologies in the last years of secondary education has not decreased, the *post-baccalauréat* choices towards scientific fields and, to a lesser degree, technological fields, shows a trend of decrease, especially in physical and chemical sciences.

These various considerations, indeed specific to France, point out to a single phenomenon: science education is in a deep crisis. First, although the system more or less continues to produce the scientific and technical *elites* the country needs, science is taught more and more as a technical collection of efficient recipes to the detriment of creativity. Second, this education fails to give to the ones who will not become scientists, engineers or technicians a proper background to understand the evolutions and to participate to the choices in a democratic society.

3. *Some lessons from 'La main à la pâte'*

This is a brief summary of the development of action in French primary schools:

- 1995: Less than 5% of French *maternelle* schools (age 3 to 5) and primary (age 6 to 11) practice any natural science.
- 1996: Georges Charpak, the *Académie des sciences* and the *Ministère de l'éducation nationale* begin a small scale experimentation called *La main à la pâte* (344 classes).
- 1998: Publication by the *Académie* of the 'Ten Principles' as a simple guide and reference for teachers. A high-quality Internet Site is developed as a resource/exchange basis.

– 2000: The experimentation has expanded as a grass-root movement and rallied over 5000 classes, with *Académie des sciences*, public and private support.
– 2000-01: Along with *La main à la pâte* and inspired by it, a new Plan for quality science/technology teaching in all schools (350.000 classes) is established by the Ministry of national education.
– 1995-2001: international developments go in parallel, in French speaking country first, then in other countries, through the network of Academies.

The Ten Principles were elaborated in 1998 and broadly diffused as a simple reference for teachers, supervisors or trainers:

- Children observe and experiment with their senses on real and close objects or phenomena;
- They are encouraged to argue and reason, to share ideas, to build knowledge;
- Proposed activities are organized in sequences, leaving ample space for children autonomy;
- A minimum science time of 2 hours/week is spent on the same theme, for several weeks. Continuity must be ensured over the 5-6 years of elementary school;
- Children keep their Experiment Notebook to write, draw with their own words and schemes;
- The goal is an appropriation of scientific concepts/procedures with language (oral & written) acquisition;
- Family & neigbourhood are closely associated;
- Scientific partners (scientists, students, engineers) accompany the teacher, but not substitute;
- The teachers vocational schools (IUFM) are involved;
- An Internet site is developed for resources and exchanges (mutualization).

Learning by doing, *Hands-on learning*, *hands & brain*, *inquiry* are parallel designation of this approach of science which *La main à la pâte* aims to develop. It is not necessary here to detail principles which are well known. It may be more interesting to quote some of the conclusions reached after five years of work, dealing with the teachers, as they represent the only real possiblity for evolution.

A few remarks need to be made here, in order to understand the background of science teaching: in the French primary schools, the teacher is polyvalent, namely he/she teaches, 26 hours a week, all the subjects, and children have only one teacher. Today, teachers are trained with 5 years after the baccalauréat, namely at the level of an engineer: their initial field may be science (a small proportion) or history, economics, litterature..., but beyond this, they all will have had two years of professional training, with barely some science (30 to 50 hours). Yet, older teachers may have had a much shorter initial training. Compulsory in-service training is limited to about 15 hours per year, while teachers are allowed to accumulate as much as 3 years of voluntary training over a 37 years career. Finally, 79% of the teachers are women. Here are a few of our conclusions:

– Teacher's attitude towards science itself is positive in principle, but often characterised by a great complex of ignorance;
– Teacher's attitude towards *teaching science* is very negative: fear, lack of knowledge, anxiety are often quoted as dissuasive obstacles;
– Teacher's are afraid, when questionned by a child, to be forced to say *I don't know*, while the child may have been exposed to scientific information on the media or in the family;
– Teacher's view on science is broken into narrow disciplines, without an integrated view of what is science and scientific behaviour. They completly ignore science history;
– Their attitude towards teaching technology is better, in the sense of 'building something which works', but they make little relation with an abstract content of the 'reasons why it works';
– They consider that science is made-up of formulas, and the mathematical expression of nature is considered as completly dissuasive of understanding what stands behind formulae;
– Best teaching sequences in science are clearly taught by teachers having no science background in their education. This is so often stated that it kills the common-sense opinion that, at this elementary level at least, science could only be taught by teachers having a strong scientific background;
– A thorough difference is observed when some kind of partnership is created and maintained between the teacher and a scientific partner (scientist, engineer, student). This partnership creates or increases teacher's self-confidence, solves difficulties about equipment or experimenting in the classroom, answers questions about scientific facts or phenomena (why is the sky blue? why is a bird flying and not falling? etc.).
– Main cognitive role of teachers is language education, as requested and easily evaluated by the parents and the system. Anything aside this

appears superfluous to the teachers. Therefore, connecting science education to language acquisition (especially the writing in the *Cahier d'expériences*, and the collective oral argumentation in discussing hypothesis or experiments) rehabilitates science as a mean, among others, to reach the language acquisition goals. Some teachers in difficult areas were quoting the fact that science writings were the longest texts children could produce!

– The number of teachers connected to Internet, either through the school or at home, is steadily increasing: developing a good site for teachers has proven to be a formidable tool for the development of science teaching. It allows exchanges of experiences, access to resources (the full 17 volumes of the *Insights* protocol, translated in French and free for dowloading, have been made available through this site). It allows also to question consultants from the scientific community or on pedagogy, and more recently cooperative work on specific subjects across the country or even worldwide (cf. the *Eratosthene* project on measuring the Earth's size with shadows). There are 350.000 teachers in French primary schools, and the *La main à la pâte* Internet site receives close to 50.000 connections per month; it handles more than 50 scientific consultants and has a forum discussion list of over 1000 teachers, while only 20% of the teachers population access Internet in 2001.
– Teachers appreciate, in very practical terms, universality of the questioning towards natural phenomena: science classes often prove to be the most efficient in giving the taste for knowledge to non-french born pupils or pupils with non-french mother tongue.
– Teachers are surprised to see that science can be taught in an integrated manner, not broken in disciplins which reminds them of their, often painful, secondary science education: dealing with *water* relates to physics, chemistry, meteorology, geology, biology of animals and plants.
– The best training of teachers is obtained, neither by giving them elaborate lectures on how to teach science, nor by step-by-step instructions which would eliminate their pedagogical initiative, but with a simple method: put them, in a collective manner, in the situation of the questioning, hypothetizing, experimenting, argumenting, writing child, and discuss with them their reactions, questions, a priori evidences, common sense, etc.
– Teacher's creativity can be trusted to enrich the initial material, draw on local resources (parents, museums, industries), improve by exchanges.

4. *Some conclusions*

The experiment started in France in 1996 is slowly progressing, and it is accepted that it may take more than one decade to seriously transform science education in primary schools. Generalization requires financial resources, a minimum equipment of 150 euros per class would lead to a total budget of 50 million euros, hundred times the 0.5 million euros spent to date in equipment. But even more, generalization requires to motivate and train the teachers. Experience shows that motivation is clearly obtained when scientific partnership breaks the teacher's isolation and fears: amplifying this partnership and finding ways to cope with the number of teachers (350 000 in France) is one of the main issues for the success. Initial training requires to thoroughly improve the academic context (vocational schools called IUFM or *Instituts universitaires de formation des maîtres*), which is not properly connected to the active science, and tends to substitute to this connection a discourse on didactics, valuable but too often cut from real and enjoyable science.

The involvement of the scientific community is also required to develop resources, create new themes based on contemporary science, relate learning to modern brain research and cognitive science (a growing field which has not been treated here, but should not be ignored), exploit the training and exchange capabilities of Internet: as a simple example the possibility to observe the night sky through a small telescope, during day time for a class, by remote observing (Hands-On Universe Project) offers entirely new perspectives to astronomy.

My conclusion is clear: improving science and technology education is in the hands of teachers, but teachers, even helped by manuals, can no longer cope alone with the pace of development. Leaving them behind means also one leaves behind whole generations of children. On the contrary, involvement of the science community and the Academies is demonstrated, through the modest effort carried in France, as a sure way to improve the situation.

APPENDIX

Note: *the following text is a short description, published mid 2001 by the French Académie des sciencies under Yves Quéré's supervision. It details the action undertaken by this Académie to rejuvenate science and technology teaching in French primary schools.*

LA MAIN À LA PÂTE (HANDS ON)

In 1995 Georges Charpak, joined shortly by Pierre Léna and Yves Quéré, launched the *La main à la pâte* (Hands-on) programme, intended to revitalize the teaching of the sciences in the primary school in France. This initiative received the unanimous support of the *Académie des sciences* in July 1996, which support has been unceasing since then.

In order to realize this objective, the Academicians have also the support of a team of around fifteen full time persons (Lamap team), of a *Scientific Council* composed of outstanding persons of research and education, and of a *Committee of partners* which is intended to give ideas and financial support to the action of the *Académie*.

What is 'La main à la pâte?'

The general idea of *La main à la pâte* is to cause children to participate in the discovery of natural objects and phenomena, to bring them into contact with the latter in their reality (outside of virtual reconstructions), directly through observation and experimentation, to stimulate their imagination, to broaden their mind and to improve their command of the language.

More precisely, here is a scenario of a typical *La main à la pâte* session.

A child has asked a question about his/her environment, inanimate or living. Instead of replying immediately, the teacher throws the question back to the class, 'And you, what do you think about it?', eliciting the hypotheses of the children and thus firing their imagination.

A simple experiment (observation, manipulation, measurement..., what you will) is then begun. Led by the children in small groups, it must in principle provide the answer, doubtless making them return to the initial hypotheses, and giving rise to the dialectic of reasoning and experiment which lies at the very heart of all research work.

Finally, the children will be invited to express their thoughts (short statements, writing in an experiment book) on the little adventure they have just experienced together, being thereby obliged to enrich their vocabulary and refine their logic and, hence, their syntax.

Of course, this is an ideal scenario which, in many cases, may be severed from one of its elements. For example, experimentation on living things (or on astronomical objects) raises specific problems. The experiment may even fail, in which case the teacher will give the answer to the initial question ex cathedra. Nevertheless, the fact remains that a personal engagement by the child, appealing at the same time to both his/her senses and intelligence, tends to encourage an enjoyment of science and bring it to life for him/her.

Hands on (and the eye in the microscope) in a school of Montreuil (Seine-Saint-Denis).

Based on these general ideas, a number of partners were sought, actions were initiated and tools created. At the same time, stimulating relations have been established with foreign colleagues working in the same vein, thus leading to collaborations and enriching comparisons. On all these points the *Académie* has contributed greatly to the progression of these ideas and to the facilitation of contacts between the partners in the operation.

The 'Académie's' partners

– The first of these has of course been the French national Ministry of Education. The launch of *La main à la pâte* in September 1996, was by Ministerial decision and involved 450 primary school teachers in five French *départements*. The number of teachers is currently more than 6,000.

Encouraged by the Department of School Education (*Direction de l'enseignement scolaire*, DESCO), the experiment led to the setting up by the Ministry, in June 2000, of a plan derived from *La main à la pâte* to revitalize the teaching of the sciences, in *all* French schools at *cycle 3* (final two years of primary school), the idea being to then extend it to all primary education, including preschools.

The *Instituts Universitaire de Formation des Maîtres* (IUFM) are essential partners because that is where the teachers are trained. The *Académie* has established excellent relations with the IUFM, concretized in the creation of a network of *La main à la pâte* 'corresponding members', with a presence in each Institute.

The *Institut National de Recherche Pédagogique* (INRP, national institute for educational research) has been involved from the beginning through research staff, IT support (see *The site*),...

The *Corps des Professeurs des écoles* (ensemble of schoolteachers) is a crucial interlocutor for the *Académie*. This dialogue is established at numerous sessions, conferences, education days..., when the promoters of *La main à la pâte*, invited to talk science, receive comments and ideas in exchange.

The *École Normale Supérieure* (ENS-Ulm) has thrown itself alongside the *Académie* in this approach, involving *agrégation* candidates (the highest competitive examination for teachers in France), and making offices available to the *Lamap* team.

– The Ministry of Foreign Affairs is an important partner of the *Académie* for the international part of the programme (see later).

– A number of the Grandes Écoles have joined the movement: l'*École des Mines de Nantes* , Director: R. Germinet, which is generating educational material, l'*École Polytechnique* some of whose students spend a few months in schools in difficult areas; l'*École de Physique et Chimie Industrielle de la* *ville de Paris*, whose Director Pierre-Gilles de Gennes has encouraged it to be involved in scientific support of a number of schools in Paris.

– Various Bodies and Associations, both public and private, support *La main à la pâte* in diverse ways, every one very effective.

The Department of Technology (*Direction de la Technologie*, DT) of the Ministry of Research, and the Interministerial Commission on the Town (*Délégation Interministérielle à la Ville*, DIV) have contributed to the financing of some of the *Académie*'s activities.

The *Fondation des Treilles*, with its hosting of seminars, and through the publication of books, has been a partner from the beginning, together with the *Société Française de Physique, EDF, France-Télécom,...*

Many Institutions are striving towards the popularization of science among children. *La main à la pâte* has positive relations with *L'explor@dôme* (Paris), *Ébulliscience* (Vaulx-en-Velin), *Science en fête, Les petits débrouillards...* and, of course, *La cité des sciences et de l'Industrie* (La Villette) and *Le Palais de la Découverte* (Paris).

In a less institutional way, many laboratories and research centres..., together with engineers and researchers (both active and retired), lend a valuable support, generally involving actions in schools or on the Internet Site (see later).

The educational tools

– The *Académie* has undertaken, with INRP, to provide French schools with an Internet network, enabling the teachers involved in *La main à la pâte* to link up with one another, and also linking them to the world of research.

The site (http://www.inrp.fr/lamap), which has three sections (information, resources, exchanges) has several attached networks:

The *La main à la pâte* network: a national site and departmental sites display locally produced resources and general information.

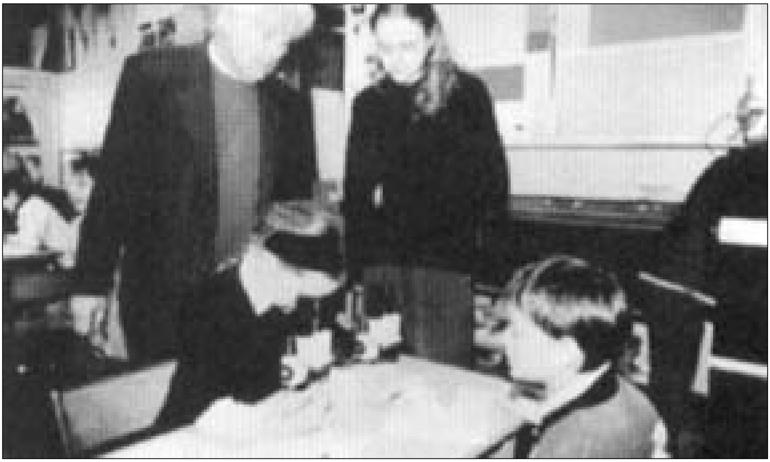
The network of *scientific consultants*: researchers and engineers answer science questions raised by teachers.

The network of *training officers/teaching specialists*: questions on teaching and education are dealt with here.

An international site in under elaboration

– Since, in the beginning, the availability of educational documents corresponding to the approach described here was only fragmentary, American *Hands on* texts have been translated and made available to teachers on the Site. Then, the generation of texts, books, experimentation packs,... has been encouraged. A 'Seal of approval committee' has been created. Chaired by Marc Julia, it examines documents seeking to achieve the *La main à la pâte* seal, which guarantees their good scientific quality.

– An Autumn university has been founded, with the support of the *Fondation des Treilles*, which brings together schoolteachers and researchers. The reports of the latter are published in the *Graines de sciences* collection.



La main à la pâte prize giving in the *Académie*.

– *La main à la pâte* prizes are awarded annually by the *Académie* to classes for high-quality achieve-ments in science teaching and learning.

– A travelling exhibition on the *History of the teaching of the sciences in schools* is planned. It will tour France from 2002.

International implications

Numerous countries, including both some of the richest and some of the poorest are also facing the need to revitalize their system for teaching the sciences.

The *Académie* has established a large number of collaborations on this theme, all the more so because the IAP (*InterAcademy Panel for interna-*

tional issues, see *International relations* sheet) has made this one of its priority tasks. Among these collaborations, it is particularly pertinent to mention those established with Brazil, China, Columbia, Egypt, Israel, Morocco, Mexico, the United States, Vietnam..., and, more generally, with the ICSU (*International Council of Scientific Unions*) through the CCBS (*Committee on Capacity Building for Science*).

One sign of this broad opening up is that the book *La main à la pâte* (Flammarion, 1996) has been translated into Arabic, Chinese, Portuguese and Vietnamese (translations in Spanish, Hungarian and Romanian being in preparation).

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EXPERIENCES IN MEXICO IN THE USE OF HANDS-ON, INQUIRY SCIENCE EDUCATION SYSTEMS IN PRIMARY SCHOOLS

GUILLERMO R. FERNÁNDEZ DE LA GARZA

Introduction

Since 1995, different activities have been undertaken in Mexico to explore the application of Hands-On Inquiry Centered Systems (HOICS) for Primary Schools with the support of the Mexican Academy of Sciences and in close collaboration with the National Academy of Sciences of the United States.

Twelve Units of the Science and Technology for Children (STC) curricula developed by the National Science Resources Center have been translated and adapted to Mexican conditions. Close collaboration has been established with several groups in the United States including school districts, universities and research institutions that have been working with HOICS in the United States.

As a result of the series of research activities, national and international conferences as well as pilot programs in different Mexican States, there is now wide interest in these systems and in the ways to insure their adequate application in Mexico.

A brief account of these experiences will be introduced in this presentation, considering their implications for other countries with conditions similar to Mexico.

An outline of possible international collaboration schemes will also be given based on the results of the International Conference on Research related to Science Education held in Monterrey, Mexico, in September 2001.

Adaptation of STC units to Mexican programs and schools

After the analysis, translation and modification of the initial 6 STC units that were selected for the pilot programs in Mexico in 1995, a research project was made applying one unit per grade of the STC in 8 schools in Mexico City.

In this research project, special care was given to the analysis of:

– The pedagogical strategies of teachers and the support they need to improve them.

– Techniques to use children's interest to cover several areas of the education programs.

– The evaluation of children's results.

There was great concern that the teachers would not be able to apply these systems in the classroom. Would it be possible for the teachers to feel confident teaching hands on, inquiry science? Would they be able to apply the pedagogical strategies needed to work with these systems? The main findings of this research are the following:

1) Teachers already have a good background in the pedagogical theories involved and are able to work effectively with these systems if they have adequate preliminary training in the details of the pedagogical objectives and scientific contents of each unit as well as continuous support during the application.

2) Teachers could easily relate important themes from other subjects like language, mathematics, geography and history with the work that the children were doing in each unit. It became particularly interesting to see that the notebooks with the written description of the children's experiences and ideas were a very good way to help them to improve their writing and communications abilities. In other cases, the use of measurements, comparisons, tables and graphs facilitated the introduction and use of mathematical concepts.

3) The evaluation of the children was seen as a very significant challenge. There was the need to go beyond the evaluation of the answers that the children could give to questions on the scientific content of the units. It was necessary to evaluate if the children had gained the thinking skills and developed the scientific attitudes that each STC unit had within its objectives.

4) Teachers require special professional development to be able to use the assessment methodologies and techniques that are appropriate for these types of science education. This is especially the case in the assess-

ment with the observation of the children in the classroom and with the tests which the children are requested to solve problems using the knowledge and skills that they have gained.

5) There was much interest to find which ways the teachers can use the pupil's interest in the STC units to deal with other subjects that are also important in the education programs.

A support system for STC applications was derived from the research results, including:

– Training workshops.

– In classroom support of a science assistant, in the first application of a Unit, to prepare and distribute materials and also to help the teacher in the review of the scientific content of the unit.

– Pedagogical advisory support to the teacher by an advisor who every two weeks visits the classroom, reviews with the teacher the work of the students and the teacher's pedagogical strategies.

– Complementary guides to facilitate the broadest possible coverage of the objectives and subjects of the official programs, linking them with the content of the STC units and the interest of the children.

The use of these support systems were found to be very important in reducing the fears of the teachers about teaching science or being exposed to questions that they could not answer properly. These support systems were also very important in facilitating the improvement of teacher pedagogical skills, especially through interaction with the pedagogical advisors, through cooperation among teachers and through additional courses and lectures that the teachers might require.

Application of the STC in Mexico

After the initial pilot applications were made in Mexico City in 1995, pilot programs were established in the states of Queretaro and Veracruz using the methodologies derived from the research project. In these cases, the local school for teachers participated in the preparation of the pedagogical advisors and in the follow up to the results in the classrooms. The science assistants were students of the last semesters of the science programs in the local universities. These assistants received training on the system, on the specific STC units that they were going to use and on the environment in the school to insure that they interacted properly with the school support system.

In the five years after 1995, STC has been applied by more than 2500 teachers in 210 schools. This has been done with the support of the local state governments and in some cases of Mexican business companies, like Resistol, Bacardi and PEMEX.

Some of the main results that have been observed are the following:

– The STC work in the classroom is curiosity driven and can be guided by the teacher to be really effective in the development of cognitive skills and scientific attitudes

– Children become enthusiastic about science and technology by exploring, discovering and making things work.

– Science taught in this way is a good support for teacher in helping students to write, to read, to deal with essential mathematics concepts and to learn about geography, history and other subjects in the general curriculum.

– Children and teacher share the need to explore, investigate and to build on previous knowledge and new experiences

– Children modify their previous schemes and enrich their possibilities to build new doubts and new knowledge that launch them to new challenges.

The STC has been used in rural areas with the same type of results and even with street children, 'CHAVOS'.

Work with Street Children

It is important to mention that in the work with street children it has been found that:

– These types of systems help the children to recognize that the knowledge that they have already developed during their childhood and their street experiences is valuable and can be the basis for them to learn more and to be better.

– There is a cooperative and respectful environment that facilitates the sharing of ideas and the development of interpersonal skills.

– Children are stimulated to express themselves with confidence, both to express doubts and to communicate their ideas.

– The children assume a reflexive, critical, inquisitive and proactive attitude.

– They improve their thinking skills and their ability to use their previous knowledge as well as their resources and tools.

– Working with the Ecosystems unit, they identify themselves with other living beings and feel that they are part of an ecosystem.

The key element in obtaining these results were the 'facilitators', specially trained young professionals performing the role of the teacher and very committed to helping the street children to overcome this situation. The pilot work with street children was organized with specialized groups and with the support of the local Catholic Church programs.

There is the possibility to use these experiences with street children to design better programs. There is the pedagogical challenge to make the previous knowledge of the children and the knowledge gained with these programs a source of confidence, self-esteem and a basis for the Chavos to:

- Find new ways to live with young people and with the community
- Become responsible for guiding and building their own lives
- Have values to improve their life and to contribute to the community.

Recent application of the STC in private and public schools

Several private schools have started using the STC in a continuous way; however, most of the applications have been made in public schools as part of demonstration programs where the schools have worked with the STC only during one year. This has happened because there has not been a federal program to support the application of these systems and because of the limitations imposed by the existing education programs and working conditions.

In the last two years, with the participation of the United States-Mexico Foundation for Science and with the financial support of the Brystol Myer Squibb Foundation, several departments of education in Mexican States have become interested in setting up permanent HOICS programs and the federal education authorities have become interested in facilitating this process.

At the moment there are already continuous applications of the STC, including the operation of pilot Science Resources Centers, in the States of Tamaulipas, Quintana Roo and Querétaro and plans to establish more in the State of Nuevo Leon and in Mexico City.

Within the education research community in Mexico there is now better awareness of the importance of research in facilitating the work with these types of systems and to improve them according to the local conditions and experiences.

A Mexican Foundation, similar to the National Science Resources Center of the United States, has been proposed in order to facilitate the understanding and application of HOICS with support from the Federal Government, the Mexican Academies and several private foundations.

Dissemination and outreach of science education improvement opportunities

In order to facilitate the understanding of the essential elements and the benefits of the new HOICS, a series of meetings and lectures were organized with teachers, education officials, business leaders and other influential persons.

Two national conferences were organized, one in Queretaro in 1997 and the second one in Xalapa in 1999, to review the content, results and possibilities of HOICS where the U.S. experiences were also presented.

Especially important was the International Conference on Research Related to Science Education held in Monterrey, Nuevo León in September 2001. The Conference was organized by the Mexican Secretary of Public Education, together with the US-Mexico Foundation for Science, the Mexican Academy of Sciences and the Government of the State of Nuevo Leon. The support of the National Academy of Sciences and the National Science Resources Center of the United States were very important, as well as the collaboration with the Inter Academy Panel, and the Latin American Academy of Sciences.

The goals of the International Conference were to:

– Analyze and discuss cognitive research findings about how people learn and the implications of these findings for teaching science to students.

– Review and discuss research findings providing evidence of the impact of HOICS on student achievement.

– Recommend effective roles for the scientific and engineering communities in working with educators to improve science education.

– Identify strategies for international cooperation in research and implementing strategies for improving science education programs.

Some of the important conclusions derived from the conference are the following:

About research on 'How People Learn':

– There are very important practical consequences in the classroom of the research results about the relationships within mental structures, the way they evolve and function, and how they are applied to common problems.

– There are very important benefits for the students if the learning environments are centered on the development of learning capabilities.

– A well-structured curriculum emphasizes the children's acquisition of essential concepts (big ideas).

– It is essential to have evaluation methods that support learning.

On the results of the TIMSS Studies:

– A very significant factor in explaining the good performance of the students is that the curriculum should be presented with depth, rigor, coherence and should challenge the student to go beyond.

– International comparison is not important *per se,* but as a way to learn how to improve and to share experiences.

– Good science and mathematics education can be achieved with limited resources and has a very important role in the development of thinking skills and scientific attitudes essential for the future success of the student in the modern world.

– We all have the moral imperative to give the world's children the learning capabilities needed to build their future.

With respect to HOICS systems:

– They have an extremely important impact in the development of children's essential learning abilities.

– There is the need to have more comprehensive studies to assess the systems and to validate their success before the whole community.

– There are very good opportunities for international collaboration on these systems, both in research and in innovation projects.

On the role of science academies in the improvement of science education:

– They are a stable platform for the discussion and promotion of improvements.

– They provide continuity in science education research and innovation, which transcends political changes.

– They offer a direct and cordial link between scientists and educators.

– They symbolize a seal of excellence when they support research and development projects in science education.

Partnerships for science education improvements:

– The importance of linking both business and society in general with science education enhancement processes.

– Acknowledge the leadership role that the business community might have in science education innovation and reform.

Final remarks

The application of HOICS in the primary and secondary schools of Mexico is seen as a very important opportunity to develop the scientific attitudes and thinking skills of children as well as to help them construct essential scientific concepts and to be enthusiastic about science and technology.

It is not easy to introduce these types of systems. It is necessary to integrate them properly to the educational programs and to work with the education authorities, the teachers and the community to set up the systemic programs that are needed.

International collaboration is a very important support in facilitating the understanding, development and application of HOICS for children.

SCIENCE FOR CITIZENSHIP

JONATHAN F. OSBORNE

Science Education and its problems

It is Collins (2000) who most aptly points to the horns of a trilemma on which science education sits. That is that science education attempts to wrestle with three mutually contradictory requirements. On the one hand it wants to demonstrate the tremendous liberatory power that science offers – a combination of the excitement and thrill that comes from the ability to discover new knowledge, and the tremendous insights and understanding of the material world that it provides. Yet its mechanism for achieving this aim is to rely on a dogmatic, authoritarian and extended science education where students must accept what they are told as unequivocal, uncontested and unquestioned. Only when they finally begin practising as scientists and enter the inner sanctum will the workings of science become more transparent. Moreover, its foundationalist emphasis on basic concepts rather than the grand ideas of science means that any sense of its cultural achievement is simply forgotten. The consequence, as argued in the report *Beyond 2000: Science Education for the Future* (Millar and Osborne, 1998), was that:

> We have lost sight of the major ideas that science has to tell. To borrow an architectural metaphor, it is impossible to see the whole building if we focus too closely on the individual bricks. Yet, without a change of focus, it is impossible to see whether you are looking at St Paul's Cathedral or a pile of – bricks, or to appreciate what it is that makes St Paul's one the world's great churches. In the same way, an over concentration on the detailed content of science may prevent students appreciating why Dalton's ideas about atoms, or Darwin's ideas about natural selection, are among the most power-

> ful and significant pieces of knowledge we possess (Millar & Osborne, 1998, p. 13).

The outcome is that science education is, in a non-too trivial sense, science's worst enemy leaving far too many pupils with a confused sense of the significance of what they have learnt and, more seriously, an enduring negative attitude to the subject itself (Osborne & Collins, 2000; Osborne, Driver, & Simon, 1996). None of this matters for the traditional education of the scientist which demands a lot of routine and rote learning to acquire the basics of the domain.

The result, however, is that such an education ignores or neglects the third horn of its trilemma, the requirement to provide its students with some picture of the inner workings of science. Knowledge, that is, of science-in-the-making (Latour, 1985) – knowledge which is essential for the future citizen who must make some judgement of reports about new scientific discoveries and applications. Contemporary society, it is argued (American Association for the Advancement of Science, 1989; Jenkins, 1997; Jenkins, 1998; Millar, 1996. Millar & Osborne, 1998), requires a populace who have a better understanding of the workings of science enabling them to engage in a critical dialogue about such issues and arrive at considered decisions about the political and moral dilemmas posed by science. New developments in science will, for instance, require the ability to distinguish whether an argument is sound: to differentiate evidence from hypotheses, conclusions from observations and correlations from causes.

Another aspect of concern is the gulf between science-as-it-is-practised and science-as-it-is-taught in schools. The growing gulf between these two is well-illustrated by our recent research (Osborne & Collins, 2000). Many pupils expressed antipathy to topics such as the periodic table. Not only did they experience difficulty in memorizing the constituents of the table, but they also failed to perceive its relevance to their everyday lives at present or in the future for instance:

> Edward: It doesn't mean anything to me. I'm never going to use that, It's never going to come into anything, it's just boring.

Similar sentiments were expressed about the inclusion of the blast furnace in school science:

> Roshni: The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it? You're not going to come across it ever. I mean look at the technology today, we've gone onto cloning, I mean it', a bit away off from the blast furnace now, so why do you need to know it?

The lack of perceived relevance to pupils' lives of such topics was a recurring theme throughout these discussions in all groups, either for continuing education in science and/or career aspirations. For instance, it was argued by a boy not continuing with science post 16 that 'I won't need to know all the equations or the chemicals. Without the essential ingredient of relevance, sustaining interest is difficult, if not impossible.

The emphasis of school science on consensual, well-established science, means that there is no space for any consideration the science that dominates contemporary society-the science and technology of informatics, CD-ROMs, mobile phones, lasers, health and disease, modern cosmology, modern imaging systems using computerized techniques, advances in materials technology and polymers, and last but not least, advances in medical genetics. This is the science that interests adolescents and would be included if the curriculum was, instead, organized around the question 'what makes young people want to learn science?' Yet there is as much chance of finding any contemporary science on the curriculum as there is water in a desert. This is not to argue for a curriculum based totally on contemporary science but simply for some aspects to be included as a vital point of engagement.

More fundamentally, the question needs to be asked how this gulf between school science and contemporary science has emerged. My analysis is that, as currently practised, science education rests on a set of arcane cultural norms which inhibit change and adaptation. These are 'values that emanate from practice and become sanctified with time. The more they recede into the background, the more taken for granted they become' (Willard. 1985). A closer examination, and the insights of contemporary scholarship, expose these norms to be nowhere near the self-evident truths that we may think-what I might choose to call the eight *deadly sins of* science education. For in contemporary society, research would indicate that trust in science is dependent on developing knowledge not only of its basic concepts and ideas of science, but also *how* it relates to other events, *why* it is important, and *how* this particular view of the world came to be. Any science education which focuses predominantly on the intellectual products of our scientific labour – the facts of science – simply misses the point. Science education should rest, therefore, on a triumvirate of a knowledge and understanding of:

a) the scientific content;

b) the scientific approach to enquiry;

c) science as a social enterprise – that is the social practices of the community.

Evidence would suggest that in many countries, normative practice regards school science education as a selection mechanism for the few who will become the future scientists of contemporary society. Consequently, the predominant emphasis is on the content of science and consensual well-established knowledge. Contemporary science – the science that interests adolescents – is notable by its absence. The result is a curriculum with only marginal relevance and extrinsic instrumental value for a limited set of career aspirations rather than a discipline valued for its intrinsic interest. Western societies can ill afford the consequent alienation and disengagement with science that such courses generate. First on the economic front, the lack of recruits into science and technology is in danger of undermining economies which are highly dependent of the skills and knowledge of these disciplines. Second, the ensuing lack of engagement and ambivalence to science threatens science's relationship with its public. Indeed, and the growing distrust of scientific expertise is in danger of placing unwarranted restrictions on future research and technological development. Moreover, fear of the worst is leading the public to demand a naïve application of the precautionary principle to research potentially limiting the advancements that science offers for solving the plethora of problems that face contemporary society. In the UK, for instance, significant pressure groups have argued that all research on genetically modified food should be halted using highly questionable ethical arguments.

What then are the norms that hinder the development of current practice in science education obstructing the development an appropriate understanding of science, a more positive engagement with the fruits of scientific labour, and a critical but constructive, understanding of its strengths and limitations? The argument here is that the practice of science teaching rests on eight fallacious assumptions which are as follows.

The fallacy of miscellaneous information

All too many science courses have attempted to make students memorize a series of dry facts which no practising scientist knows, such as the boiling point of water, the density of various substances, the atomic weight of different chemical elements, conversion factors from one system of units to another, the distance in light years from the earth to various stars (and so on). However, an increasing body of work now shows that knowledge is only one component of the many competencies required of adults in their professional life and, unless it is constantly used, is rapidly forgotten (Coles, 1998; Eraut, 1994).

The foundational fallacy

This is the fallacy that because scientific knowledge itself is difficult and hard won, learning and understanding science requires a similar process where the student's knowledge and understanding are assembled brick by brick, or fact by fact. As a consequence, only those that reach the end ever get to comprehend the wonder and beauty of the edifice that has been constructed. Current practice, therefore, is rather like introducing a young child to jigsaws by giving them bits of a one thousand piece puzzle and hoping that they have enough to get the whole picture, rather than providing the simplified 100 piece version. In effect, although the pupils can see the microscopic detail, the sense of the whole, its relevance and its value-the things that matter to the pupil (Rowe, 1983) are lost. Chown (1998) offers a good example of a tale which the foundationalist approach offers only to undergraduates or postgraduates taking courses in stellar nueleosynthesis – the grand ideas of science which are reserved only for those who complete the course.

> But if all these examples of our cosmic connectedness fail to impress you, hold up your hand. You are looking at stardust made flesh. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath – all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Every one of us was, quite literally, made in heaven (Chown, 1998, p. 62).

Yet there is nothing about such a story which is intrinsically difficult. The failure to communicate such ideas in compulsory science education simply reinforces Claude Bernard's, the famous 19th century philosopher, view that science is a 'superb and dazzling hall, but one which may be reached only by passing through a long and ghastly kitchen'.

The fallacy of coverage

School science is suffering from a delusion that the science we offer must be both broad and balanced. The result is an attempt to offer a smattering of all sciences and to cram more and more into an oft-diminishing pot. Quite clearly, as the bounds of scientific knowledge expand from evolutionary biology to modern cosmology, more and more knowledge vies for a place on the curriculum. However, just as those teaching literature would never dream of attempting to cover the whole body of extant literature, choosing rather a range of examples to illustrate the different ways in which good literature can be produced, has the time not come to recognise that it is our responsibility to select a few of the major *explanatory* stories that the sciences offer'? And surely it is the *quality of* the experience, rather than the quantity, which is the determining measure of a good science education?

The fallacy of a detached science

Science education persists with presenting an idealized view of science as objective, detached and value free. This is wrong on three counts. First the public, and particularly young people, do not distinguish between science and technology. Second, science is a socially-situated product and the language and metaphors it draws on are rooted in the culture and lives of the scientists who produce new knowledge. Thirdly, those that engage in science are not the dispassionate, sceptical and disinterested community that Merton (1973) portrays. Science is a social practice, engaged in by individuals who share a 'matrix of disciplinary commitments, values and research exemplars' (Delia, 1977). Within the contemporary context, where scientists are employed by industrial companies with vested interests, it is hard to advance a case that science is simply the *pursuit of truth* untainted by professional aspirations or ideological commitments. For these days scientists are:

> judged as much by the company they keep as the data they may gather (Durant & Bauer, 1997).

Finally, the separation of science from technology eliminates all consideration of the societal implications for society. For, as Ziman (1994) argues, if science education fails to make the small step from science to its technological applications, how can it take the much larger step to the implications for the society in which it is embedded?

The fallacy of critical thinking

This is an assumption that the study of science teaches students reflective, critical thinking or logical analysis which may then be applied by them to other subjects of study. It is based on the fallacious assumption that mere contact with science will imbue a sense of critical rationality by some unseen process of osmosis. It is also an assumption questioned by the Wason 4 card problem and the Wason 2, 4, 6 problem

(Wason & Johnson-Laird, 1972) both of which require a standard scientific strategy of falsification to determine the correct answer and, which very few, including scientists, use.

Secondly, the notion that science develops generalizable, transferable skills is also an assumption questioned by the body of research which suggests that people's use of knowledge and reasoning is situated within a context (Carraher, Carraher, & Schliemann, 1985, Lave, 1988; Seely Brown, Collins, & Duiguid, 1989) and that detached knowledge is of little use to individuals until it has been reworked into a form which is understood by the user. More fundamentally, the dogmatic and authoritarian training required for future scientists only permits original and critical thought once its noviciates begin to engage with original research. Prior to this point, there is little to incentive to engage in critical enquiry.

The fallacy of the scientific method

This is the myth that there exists a singular scientific method whereas the record of those who have made the important discoveries of the past shows not only that scientists rarely attempt any such logical procedure, but that the methods vary considerably between the sciences. The methods deployed by the palaeontologist working out in the field are about as similar to those used by the theoretical physicist as chalk and cheese.

Yet the science that increasingly confronts the individual in the media, with its focus on environmental or biological issues, is predominantly based on correlational evidence and uses methodological devices such as clinical trials with blind and double-blind controls. Yet where, and when, is there any treatment of the strengths and limitations of such evidence (Bencze, 1996)? Is it not time to give up any notion that there is such a singular entity and turn instead to presenting a range of ideas about science and its working. Moreover, when so much of the science reported in the media is based on epidemiological research and associative findings – probability and likelihood rather than causal relationships and certainty – is it not time to teach about such data, its interpretation and evaluation?

The fallacy of utility

This is the myth that scientific knowledge has personal utility-that it is essential to the mastery of the technology; to remedy its defects; and to live at ease in the culture of technology that surrounds us. For as machines become more intelligent they require less care and thought for their effective use. Even its economic utility is questionable as current employment trends, at least in the UK and USA, suggest that, although we will need to sustain the present supply of scientists, there is no indication that there is any need to significantly improve the number going into science, which remains, as ever, a small minority of the school cohort of around 10-15% (Coles, 1998; Shamos, 1995).

The homogeneous fallacy

Increasingly, in many countries, science education labours under the fallacy that its clientele are an entity who, whilst they might differ in aptitude and ability, nevertheless are best served by one homogeneous curriculum. With their devotion to pure science, a foundationalist approach, and a high-stakes assessment system, the result is a pedagogy based on transmission (Hacker & Rowe, 1997). By the onset of adolescence, the imperative of relevance increasingly challenges the delayed gratification on which such a curriculum rests leading to a lack of motivation and interest (Osborne, Driver, & Simon, 1996). Pupils, therefore, need to be offered a diversity of science courses to meet their disparate needs.

What then are the methods, practices and components of a new vision of science education that might meet these concerns? The broad framework of such a vision has been developed in the report *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998). In this report, we argued for 10 recommendations, which we saw would address many of the aforementioned criticisms. These were:

1) Science education should be for the majority and should be for scientific literacy.

2) An element of choice should be allowed at age 14.

3) The curriculum needs aims to ensure that its primary purpose is well understood and shared by all.

4) Scientific knowledge can best be presented as a set of explanatory *stories* that would provide a holistic overview of the great ideas of science.

5) Technology can no longer be separated from science as the former is what interests pupils.

6) The science curriculum must give more emphasis to key ideas-about science.

7) Science should be taught using a wide variety of teaching methods and approaches.

8) Assessment needs to measure pupils' ability to understand and interpret scientific information.

9) Change in the short term should be limited as radical change is undermined by teachers.

10) A formal procedure needs to be established for the testing and trialling of innovative approaches.

This report has been read widely and positively received influencing some of the changes in the new version of the English and Welsh science national curriculum and requiring greater exploration within school science of the relationship that exists between ideas and evidence (Department for Education and Employment, 1999). It has also led to the development and piloting of a new course for 14-16 year olds which will have a specific focus on science for citizenship. Perhaps, more significantly, the report has the support of the UK Deans of science committee who stated recently that:

> 'Broadly we agree the analysis presented in the report Beyond 2000: Science Education for the Future ... We are acutely aware that the style of specialist school science curriculum has not changed for many years. We thus have to recognise that an approach that worked satisfactorily in the past as a preparation for higher education no longer does so in the changed social and communications environment of today ... From a higher education science perspective, therefore, we l would happily see the general approach advocated in the Beyond 2000 report applied to the entire secondary science curriculum'.

For this report to gain acceptance from the representatives of the academic scientific community is a major achievement for it is this community that are the major stakeholders in the science curriculum. That they too seek change is an important recognition of the failings and inadequacies of the current system.

However, reforming the science curriculum to meet the challenges of the contemporary society faces a number of obstacles that must be addressed and met. These are the limitations of the qualifications and abilities of the science teaching force; the problems with developing appropriate modes of assessment; the resistance of well-established stakeholders., and the culture of science teaching.

Curriculum Reform

Any new curriculum which gave more emphasis to developing an understanding of the nature and processes of science, would require teachers themselves to have some understanding of these dimension of science. Yet science teachers are the products of an education which has paid scant regard to history, or any examination of its social practices. And for good reason-the dominant ideology within science is one of dogmatism and authority where the tentative nature of the roots of scientific knowledge is excised to present science as a body of certain knowledge which has been the successful, linear progression of the work of isolated great men, devoid of any cultural context. The outcome of such an education is a body of science teachers who have naive views of the nature of science-seeing it as an empirical process where scientific theories are inductively proven (Koulaidis & Ogborn, 1995; Lakin & Wellington, 1994).

Similarly, Donnelly (1999) has shown how science teachers see their work as one which is dominated by content rather than process, as opposed to the contemporary treatment of history where the history teachers seek to develop an understanding of what it is to do history, The significance of empirical work to science, and in the teacher's practice, is such that teachers are endowed with distinctive status by the provision of specialized laboratories. Laboratories in their turn become rhetorical artefacts where the scientific world-view can be used to illustrate the predictability of nature and inspire confidence in the scientific world view (Donnelly, 1998). Asking teachers to teach more about the nature of a subject which they themselves only have a limited understanding of will inevitably be problematic.

Attempts to introduce change under the umbrella of the National Curriculum – particularly when those changes were later shown to be based on fallacious models of science – have met with substantive resistance and modification. The 1991 version of the English and Welsh science curriculum introduced a model of practical based investigatory work which was unfamiliar and resented by teachers who failed to share or understand its intentions. The result was a long period of adaptation whilst teachers reworked the curriculum to put into practice work which was a distorted representation of the intentions of the national curriculum document. Many teachers were alienated or disaffected by the process (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996).

The lesson of these problems is one that was clear from previous research on educational change (Fullan, 1991; Joyce, 1990). First, teachers must he dissatisfied with the existing curriculum if the arguments for change are to be heard. Second, if change is to occur, teachers must be supported in developing new practices, new bodies of knowledge and new pedagogic methods. At the very least, that requires the rewriting of curriculum support materials which should seek to provide exemplary illustrations of the ideas to he taught and suggestions for how it can be taught. More substantive support would require a programme of professional development delivered by individuals who are themselves competent and effective teachers who have a good grasp of any new initiative. At the very best. there would be *in-situ* training provided for all teachers who required it.

Assessment

The second problem lies with reform lies in the role of assessment within existing national and international frameworks. Within the past twenty years, political imperatives have led to the necessity to measure the performance of the educational system. The consequence has been the rise of national systems of assessment based on testing at certain key ages – in the UK these are age 7, 11, and 14. Internationally, we have also seen the rise of comparative assessment between countries which have been used as a measure of the overall quality of education (Beaton et al., 1996). Thus rather than assessment serving as a tool to benefit the child, providing either a formative or summative judgement of their capabilities, it has become a servant of a bureaucratic mentality that seeks to monitor the performance of the system. Whilst, it could be argued that these two aims are not incommensurable, the reality is different.

Similar problems have beset attempts to provide performance indicators in the Health Service, in the privatized railway companies, and in a host of other public services. In each, a variety of indicators are selected for their ability to represent the quality of the service, but when used as the sole index of quality, the manipulability of these indicators destroys the relationship between the indicator and the indicated. Directing more and more attention onto particular indicators of performance may manage to increase the scores on the indicator, but the score on what it indicates are, in reality, relatively unaffected. Thus whilst measures of children's achievement show year on year improvement, the actual quality of their education remains much the same.

The lesson of history then is that in seeking to make the *important measurable*, only the *measurable* has become *important*. The second problem is that within school science, assessment items are commonly devised by those that have been, or still are, practising science teachers. Just as it is often said that you teach only that that you can teach, so assessment is often based on the normative values of what it is considered possible to assess. Hence the assessment of students' understanding of the processes of science, or its social practices, are not considered because there is no established body of knowledge of how to assess such items. At worst, assessment experts will simply assert that it is too difficult, time-consuming or expensive to assess such understandings and, at best, that they do not know how to do so. Thus, within such a context generated by the importance of measuring performance of students, teachers and schools, the clear message to teachers is that the lack of any assessment of a given topic implies that it is an extraneous item of no significance.

The single most important message that emerges from this analysis is that curriculum reform without a commensurate change in the assessment will be ineffective. Change must be attempted holistically and not in a piecemeal fashion for the intended curriculum is read as much, if not more from the assessment as much *as* it is from the curriculum. In conclusion, what *is* evident, is that *science* for all requires a curriculum for all. The current flight from science by contemporary youth would suggest that anything else would be a price that neither science or society can afford to pay.

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THE PRESENCE AND ABSENCE OF SCIENCE IN ITALY'S EDUCATIONAL TRADITION

GIUSEPPE TOGNON

Italy is a country that boasts a fine scientific tradition and vast technical experience, yet Italian society still has difficulty in recognising itself in this picture. The basic education offered by Italian schools is good, indeed among the best in the world. The level of university education is up with that of other major nations. Italy no doubt suffers more than most the shortcomings typical of Europe as a whole: few investments in Research and Development, a small number of researchers, fragmentation in terms of organisation, few patents. This state of affairs is however in line with the general 'European paradox': a continent where the scientific base is sound, where the network of universities and laboratories is excellent, where there is a high concentration of theoretical expertise, but also where scientific discoveries and technological applications are not at the same level as those of the US or, until a few years ago, Japan.

Why then in Italy do we find it particularly difficult to accord science its rightful place? Perhaps because Italy has been the 'Catholic' country most chastised by the Church? But we know that this has not been the case for the past two centuries. Perhaps because its economic and industrial development was delayed somewhat? This is true, but it was then exceptional, and Italy managed to catch up. The causes are more complex. They are concerned with the tricky relationship between knowledge and Italian society, and have been compounded by the schooling model, adopted in 1860 when the country was unified and confirmed by the reform of the schooling system inspired by the neo-idealist philosopher Giovanni Gentile in 1923. This model is based on supremacy of the culture of the written classics and on the clear-cut distinction between literary and durable education for the emerging bourgeoisie and practical, accelerated education for the masses. The Gentile reform was important in many ways, and cannot be criticised just because it was effected during the period of fascism. The origins of this reform went back a long way, and were accepted by the majority of Italian intellectuals, including liberals and socialists. At the beginning of the 20th century in Italy, as in France and Germany, there was a revival in a philosophical movement whose aim was to establish unity around spiritual values that might overcome those of materialism and positivism. There was a violent confrontation between different schools. The neo-idealistic current came out victorious, partly because of its ability to represent the need for social emancipation of the lower middle classes that sought employment in the public sector and liberal professions. We know that a sound basic classical education, centring on the study of the arts and languages, actually helped rather than hindered the career of major scientists. The main limit of that cultural model was rather the intent to write off science categories as 'pseudo-concepts', as B. Croce said. Unfortunately such a purely instrumental conception was enormously successful, partly favoured by a certain naive Positivism. The stories of positivism-inspired science illustrated the slow but inexorable rise of scientific observation and experimental verification over religious prejudices and traditional abstract knowledge. Positivist literature stressed the benefits that the new rigorous scientific method would have on humanity, not only in cultural but also in civil, political and social terms. Such stories had dramatic contrasts: light against darkness; rationality opposed against credulousness; the truth clearly distinguished from error.

In light of these and other conditions that I cannot name here, contemporary Italian society has systematically distinguished between the 'two' cultures, theoretical and experimental, thus refuting the specific nature of its tradition. Above all, it has constructed the image of the cultured man around the model of the jurist and man of letters and the image of the influential man around the model of the politician. Notwithstanding the efforts of some pioneers, 20th century Italian society gave priority to ethical-political issues over scientific research. In Italian universities the chair of history of science or scientific techniques has existed only since 1980. The first national programme for the divulgation of a scientific culture got under way only in 1989. Hostility towards the sociology of science has meant that scientific research has been removed from national awareness.

This national weakness may also be explained by the absence of a policy defending and enhancing Italy's historical and scientific heritage. Everybody knows for instance that Italy is the nation of museums and collections *par* *excellence*. But among the thousands of public and private museums and institutions, which are cited as proof of the absolute excellence of our country, scientific museums and technological and industrial collections are rarely mentioned. After the Unity of Italy little or nothing was done in this sector to catch up with Great Britain, France, Germany or the United States. A significant breakthrough in this direction only came in the 1920s and 1930s, a time of great modernisation for Italian society. Fascism embarked on a series of initiatives to valorise Italy's scientific heritage and to disseminate a technical-scientific culture, from which all the institutions still operating in our country originated. This interest was not selfless. The Regime aimed to finally give Italian culture as a whole 'virile' and powerful guidance. It saw Italian 'supremacy', in both civil and scientific terms, as being effective for the regime's propaganda and for the celebration of Italian science. Many of the best Italian scientists were forced to emigrate. It was in this climate and with these intentions that the scientific institutions and museums that still constitute the basic framework of Italy's research system, first and foremost the National Research Council, were founded. The issue that should be stressed here is that after World War Two the new Republic basically preserved the same system. It did change internal set-ups, create new laboratories and new faculties, but it was unable to change the collective mentality. For decades Italian scientists have had to 'struggle along', being forced to perform miracles, often to emigrate or spend a great amount of energy in search of resources, available almost only from public sources. Many researchers have become – or generously turned themselves into – 'politicians', with results that have not been spectacular either for science or for politics.

We can no longer carry on this way. The world's scientific and social scenario has changed, but the problem remains that of the educational roots of science. Psychological and social sciences have shown us the importance of the cognitive and emotive mechanisms that rule the life of individuals and communities. We all know too the way in which major technological and scientific challenges have been brought to the attention of the public at large by the media. Government and non-government committees dispensing ethical-scientific advice have sprung up in all countries. The majority of general discussions are now concerned with ethical controversy born out of scientific research. And with globalisation, moratoriums just do not work in 'sensitive' areas. We are unable to ascertain whether the moratorium is universal or only affects with some countries; whether it is possible to overcome the pressure of lobbies and industrial interests; whether researchers can be persuaded to prefer prudence to speed and private interests.

Rhetorical solutions can no longer be proffered. It is always possible of course to alter teaching methods, organise more training activities, create foundations or prepare major exhibitions. Positive transformation can clearly only result from a series of coordinated actions in schools and universities. One of the basic school functions that has almost totally lost its positive influence in recent decades is the scientific laboratory. A large number of schools were and still are endowed with such laboratories. But with current research trends, the lack of funds and competent technicians and limited equipment, there has been a gradual abandonment of laboratories, and they have been sidelined from teaching activity. I personally am aware of the attempts to reform educational systems in all industrial countries over the past twenty years: too often they have fallen victim to the 'engineering' of school curricula that has failed to yield good results. As Einstein said: 'I reject the idea that schools must directly teach the specialist knowledge that will have to be used in later life. Life's needs are too many and complex for such specialist teaching to be possible. The aim of schools should always be to ensure that youngsters leave school with a harmonious personality. The general ability to think and judge independently should also take first priority'. If this is not possible for the masses, then at least we have to try to invent the new figure of 'mediator' beside the figure of pure researcher: the mediator, an invaluable scientist whom the community of researchers entrusts with the job of seeking consensus, explaining and pre-empting objections. In university departments it is necessary to re-evaluate the role of those studying and teaching the history and didactics of science, a function often assigned to second-rate scientists.

The general problems is that of educating our societies to be able to choose while the machine is running, and to select the level and nature of knowledge that such choices require. If there is an alphabet of science, consisting of specific and specialist knowledge, then there is also a 'grammar' of knowledge, which extends beyond specific areas and is concerned with the overall behaviour of men in relation to knowledge and its history. There was a time when life's choices were few, and it was often other people that decided for us: what to study, who to live with, who to do business with, who to spend time with, who to vote for. Now we are called upon to make choices about everything, every day. These are almost always simple or false choices, regarding market-oriented consumption choices. When we come across real choices, we try to brush them to one side, because we have got out of the habit of considering knowledge as the basis for choices and of encouraging mutual trust. We are no longer living at a time when the models of scientist are those of Einstein or Fermi, alone and faced by terrible alternatives, but still very cultured men alert to ethical problems. The problem with our system of specialist teaching is basically: it does not teach scientists about responsibility, it does not help the layman to appreciate scientific progress, it does not provide scientists with the tools to defend these breakthroughs when they are called into doubt.

To develop the educational roots of science, therefore, we must work on several fronts and 'from the bottom', namely at the level of individual scientists. The number of scientists should however rise well beyond the number of professionals, and scientific intelligence should become a mass phenomenon. We do not have to create a mass of researchers, but it is important to get whole populations to understand something about science, enough to be able to choose and to give or deny consensus to professionals, to involve them in the community rather than confining them to the laboratory. Without a popular scientific base, scientists too tend to intensify their individualism, and when they have to choose between cynicism and responsibility, they are torn by what are often futile internal conflicts. And without the understanding of public opinion, it is almost a waste of time calling upon scientists to reflect upon their responsibility with regard to the results of their action.

Human beings play a part in scientific research in three ways. Through the personality of the individual scientist, through the personality of scientists brought together in a community, and finally through the history of the society they are a part of. Science is not just a two-sided game, theory against nature, it is more complex, with the individual playing at least three roles: scholar, researcher, citizen. The more the person delves into science and acquires knowledge, the more responsibility and ethics circulate around the world through him.

Today science and technology are 'current money', but if the successful model of 'scientist' continues to be that of extreme competition between nations, between lobbies, we cannot hope to make of scientific research something more than other marketable occupations. If moreover public opinion continues to consider scientific research only as a means to an end, the scientist will continue to be viewed only as an economic entity, and it will attempt to unload the causes of evil onto society. There is the danger that what is happening against financial globalisation will be transferred to scientific and technological globalisation, which is the essence of the former. Then no one will be able to call himself simply 'a free scientist of a free science'.

EVALUATION AND EDUCATION IN SCIENCE

BABACAR GUEYE

1. Introduction

Be it explicit or not evaluation always comes along with teaching (oral and written tests, exam papers, etc.) That is why it may have a central position in all well-thought of curricula.

However it is common knowledge that the evaluation part is the most difficult curriculum component to set up. That is why in Education Science it has been considered as a special field of investigation for so long.

Docimology – a subject that concerns itself with evaluation in order to disclose good and bad practices and then consolidate the former and improve the latter has gradually gained ground into evaluation research.

If many researchers have tried in the past to define the evaluation concept in a more or less successful and appropriate way, today we must agree that most of them put evaluation at the service decision making (STUFFLEBEAM 1980, De Ketele 1993).

For De Ketele, evaluation means to

– collect a set of adequately appropriate, valid and reliable information

– study the adequacy rate between this set of information and another set criteria suitable to the assigned objectives from the onset or streamlined on the way, in order to make a decision (De Ketele, 1993).

This definition corresponds to an epistemological change as if nowadays a fully documented decision making seems to be the stated objective of evaluation, the unique will to pass a value judgement from measures had seemed to overrate any other considerations for a long time.

As a mather of fact value judgement and decision making are the two stages of the same process. Any decision making stems from a value judgement on the people's actions or performance in relation to implicit or explicit objectives.

Another definition of evaluation considers that it should help determine congruence between performance and objectives that is Tyler's definition stated as follows.

"The evaluation process mainly consists in determining to which extent the education objectives principally aim at changing human beings, that is the objective is to cause desirable changes in students' behaviours, whereas evaluation is the process consisting in determining to what extent these behavarioural changes are actually occurring (Tyler, 1950)".

Therefore it could be stated that the evaluation issue is mainly rooted on the following questions

What is to be evaluated?

When and why evaluate?

How to evaluate?

Our paper which is focusing on the teaching of sciences develops within that range.

2. The Traditional functions of Evaluation

2.1. *What is to be evaluated?*

The usual answer to this question is provided by the school conception that stages the following steps in the design of any programme.

– Determine the objectives that should be aimed by the course or the programme

– Choose the learning experiences that will help reach those objectives

– Organize those learning experiences

– Determine to which extent those objectives are attained (FURST, 1964).

The point is then to evaluate the objectives, more precisely the objectives in terms of behavariours if Tyler's (1950) and FURST'S (1964) definitions are brought together.

The basic task is, therefore, to assess the objectives and categorize them. All this resulted in the already familiar taxonomies (Bloom, d'Hainaut, etc) which have, each attempted to assess, describe and categorize what the learner should be able to achieve what ever subject content may be used as support.

The first taxonomy, that of Bloom published in 1956 lists six levels (knowledge, comprehension, application, analysis, synthesis, evaluation) was used in Quebec as early as 1964, then in Belgium in 1972 for evaluating learners.

Such a method had a strong point as it rationalized systematized and evaluated an educative action which had too long been left to intuition, sensibility and common sense (De Landsheere, 1975).

However that has been a major criticism against it. The use of taxonomies entails too strong a focus of evaluation and teaching on atomised behaviours which do not take into account the initiative and desire of the learner who is thus compelled to quasi inactivity.

2.2. *When and why evaluate?*

It is customary to evaluate while learning is in progress (oral & written quizzes, progress tests, etc) or on completing a syllabus (exams, contests). Those two evaluation forms use to be kept apart by SCRIVEN (1967) who calls the first on while Training Evaluation and the second End of Training Evaluation. They are different not only in terms of the time when they are administered, but also in terms of the reason for their administration in the application of teaching programmes.

The while-training Evaluation (Progress Test) may be defined as a continuing evaluation process aiming to ensure every individual's progress in a learning strategy in a view to alter the learning situation or the rate of that progress in order to improve on remediate (if applicable) it.

The end-of training Evaluation (achievement test) which tends more and more to be referred to as Certification Test is defined as the one that leads to a binary decision for a pass or fail in relation to a learning period, for granting or denying someone a promotion, for continuing or stopping an action (De Ketele et Roegiers, 1993).

2.3. *How to evaluate*

In many countries it up to the teachers in charge of one course who design the evaluation (progress and achievement) tests and the learner is supposed to demonstrate his/her competence through a written production: it is the well-known "per and paper" test.

The oral tests are indeed administered, but writing is a given more focus with a higher coefficient.

Two main techniques are usually employed in school tests

– The so-called objective test when the learner has to choose the one correct answer from others which are not. This kind of test resulted from the early applications of taxonomies, namely in Canada in 1964 and in Belgium in 1972 as far Bloom's taxonomy is concerned.

– The composition, an answer in a written form which allows the learner to produce some more elaborate response, presented in an organised or an original free way.

In the field of sciences, the composition has developed from a traditional form in one question, one sentence or one word alone to a more structured form with several questions requiring more or less complementary answers extracted from provided documents.

That change occurred while the methodological procedure was being introduced in the teaching of sciences which allows both discovering and understanding phenomena.

3. Contributions of Didactics to Evaluation

Subject areas Didactics seems to me more comprehensive and systematic to report on the impact of evaluation on the teaching of Sciences, which is the reason why I have chosen it as a scope for this discussion.

If Didactics was originally, indeed, a new approach to educational issues, it has to be noticed that it has presently expanded beyond the school field. Now it deals with all the communication settings, be they formal, non formal or unformal.

Coming back to the school setting which the object of our concern, let us consider that the Didactics of a given subject area both looks at classroom proceedings and at what happens in the learner's mind.

In short, it has to do with the way messages are encoded and transmitted, in priority, but most principally with "how learners learn" and how they interact with the learning contents and the teacher's strategies.

Didactics positions itself at the crossroads of the three following domains.

– The subject area domain (programme – contents – objectives)
– The psychological domain
– The pedagogical domain

It calls upon each of these domains if need be, to give a definition and meaning to the school tasks, depending on the obstacles facing the conception and acquisition of knowledge and skills. Today, didactics has identified two short comings in the teaching of Sciences.

First school has generally restricted evaluation to the sole field of learning.

Second, the quality of the evaluation battery in use is so poor that it has negative consequences on the whole curriculum

Be it in the form of a progress or an achievement test, evaluation in the teaching of sciences is only geared towards learner acquisitions. However, as far as the teaching field is concerned there are other contests which require the collection of reliable and valid data before decision making.

– First, it is now common knowledge that actual teaching is preceded by the teacher's awareness of his learner's ideas. Which will help him take into account libely problem areas when planning lessons.

– Second, the teaching tools used as supportive materials learning bear information and values that are worth disclosing for optimal efficient use.

– Third the different evaluation results also include useful information on learner behaviour and how it operates.

As mentioned above, evaluation in the teaching of Sciences is today confined to the results of acquisitions. Given this situation, the Didactics of Sciences, through its research results has revealed thanks to a more systematic vision of the teaching act, other fields, other instances when evaluation may play an important role in the quality of learning of teaching aids and reinforcement that may be granted as shown in the grid below.

EVALUATING MEDIATION

Mediator	What to Evaluate
1. Knows the targets	Characteristics, questions, interest, conceptions, thought procedures
2. Has objectives	Knowledge Know-how Attitudes
3. Has communication resources	Teaching aid Films Books Posters Teaching modules
4. Has constraints	Space Time Funding, etc…

3.1. *Diagnostic evaluation*

If the teacher pays some attention to “errors” made by learners on such or such a concept or scientific reasoning, he realises that some of those are made again and again on a regular basis.

It was logical for didactics to look closer at errors. This is how researchers discovered that prior to a course on a given topic learners had a number of ideas on it, their own explanations of some phenomena and interpretation of the environment surrounding them. Those prime ideas, those rough elements in the learner’s brain that most often opposed to settled scientific knowledge are referred to as conceptions or representations. The sciences didacticians started evaluating those conceptions. If the learners’ conceptions issue has been raised since the works of Piaget, its systematic study started in France only with the works of Pr. Giordan (1975, 1977, 1978) who came to realise like other researchers that learners tended to forget most of the scientific knowledge acquired at school or in other terms the “pedagogic yield” that is the amount of knowledge acquired in relations to the time spent at school is very weak, even non existant, at times. Presently over (W) three quarters of studies published in sciences didactics deal with conceptions they fall into three categories.

– *Descriptive researches*

They assess learners’ conceptions and draw up questionnaires, etc, kinds of catalogue. Unfortunately, they wank, I believe, as the most numerous.

– *Explanatory researches*

They go beyond mere categorisation of conceptions, they aim at identifying the mechanisms that generate them and how they operate.

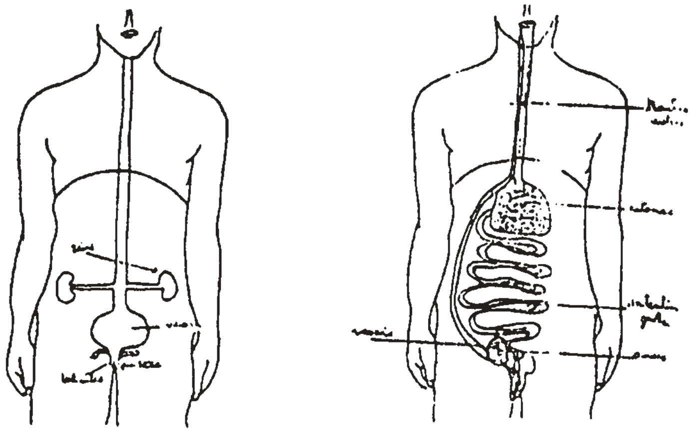
– *Applied researches*

They are few however they seems very important to me as they try to install teaching strategies usable in class and taking into account learners’ conceptions.

All these researches are credited to put the lear back at the beginning and end of the education act and have made obvious what follows.

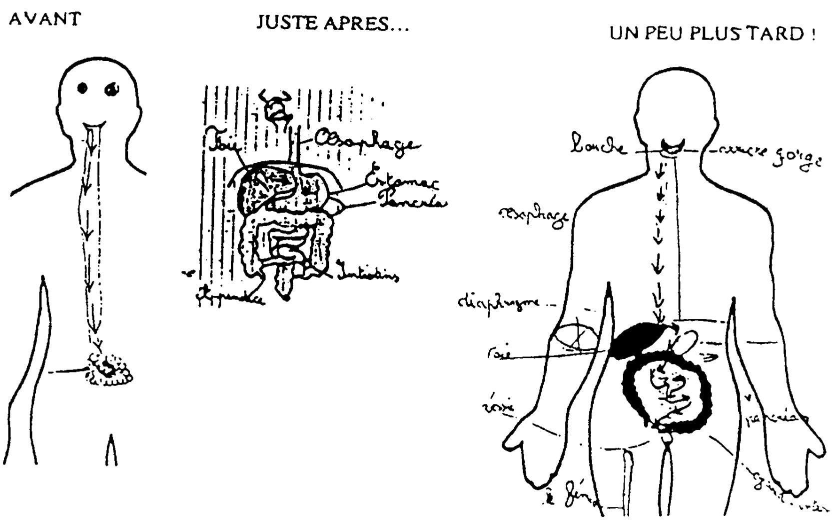
– *Before any teaching* learners have conceptions, ideas or reference framework allowing them to capture the different messages.

Here are a few examples about the digestive apparatus (Giordan, 1988).



1 2

Document 1. Two different conceptions of the digestive apparatus. In Case 1 There is a confusion with the excretion apparatus and the continuing part of the oesophagus leading to the bladder. In Case 2. Two canals (one of them would represent the trachea) One for solids – This shows that the learner is always active he always functions with prime ideas at back of his mind. Conceptions are extremely difficult to eradicate. If the teacher does not take them into account what is taught will only transit, as shown in the example below still about the digestive apparatus (Giordan, 1988).



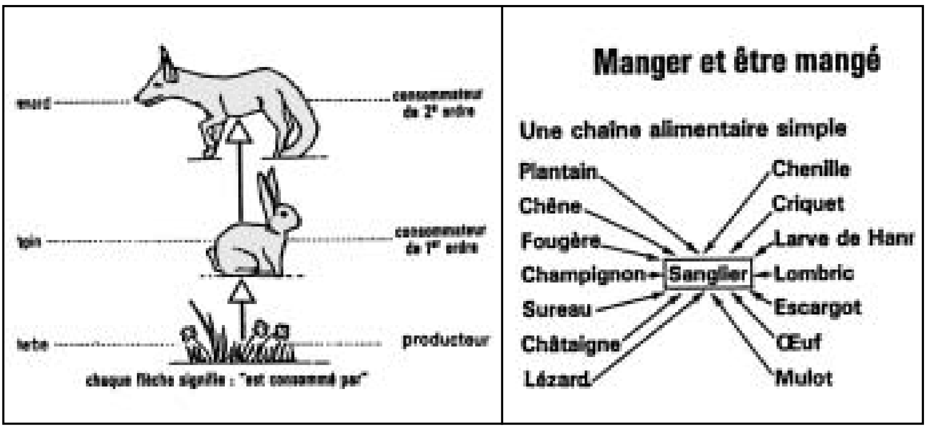
Document 2. Evolution of a conception of the digestive apparatus after the lesson.

3.2. *Evaluation of Teaching aids*

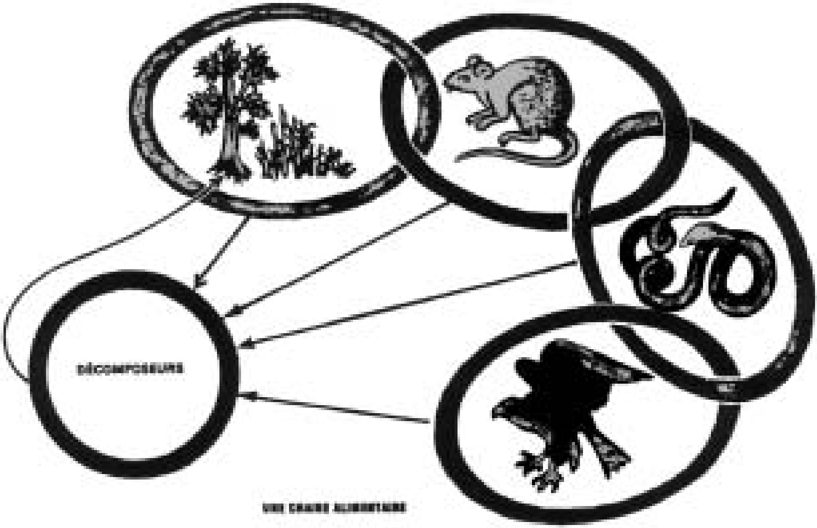
In the teaching of experimental sciences, the teacher often resorts to aids of icaried kinds in order to create situations that favour actives learning. This how he moves from exposure to demonstration at to problem solving at times. In such situations they help the teacher reach move easily the targeted objectives allowing learner to build up knowledge by themselves. They also permit to engage into activities which would not be possible, other wise.

For a number of years now, teaching research has been stressing the fact that teaching materials (books, films) carry information and even values that deserve evaluating before use not only avoid embarring situations but to assess their efficiency. Here are a few examples taken from school text books.

EXAMPLE 1.

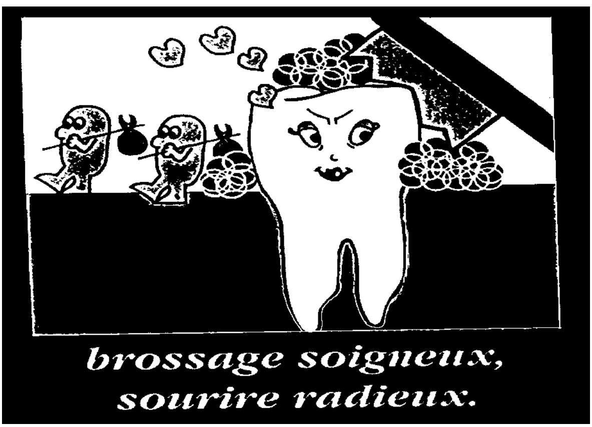


Document 3. The food chain in ecology. If the drawing on the left may be receivable for its simplicity, that on the right is hardly acceptable. Moreover, judging from terminology familiar to learners, this has nothing to do with a “chain” – “Chain” refers to a sequence of rings as shown below.



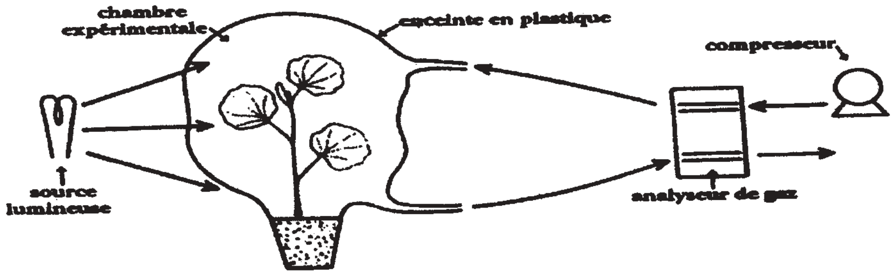
Document 4. Another representation of the food chain concept. But here, the arrow does not mean “is consumed by”. This is a semantic and conventional puzzle which needs to be evaluated and straightened up for a better understanding of the food chain concept.

EXAMPLE 2. Information about tooth hygiene.

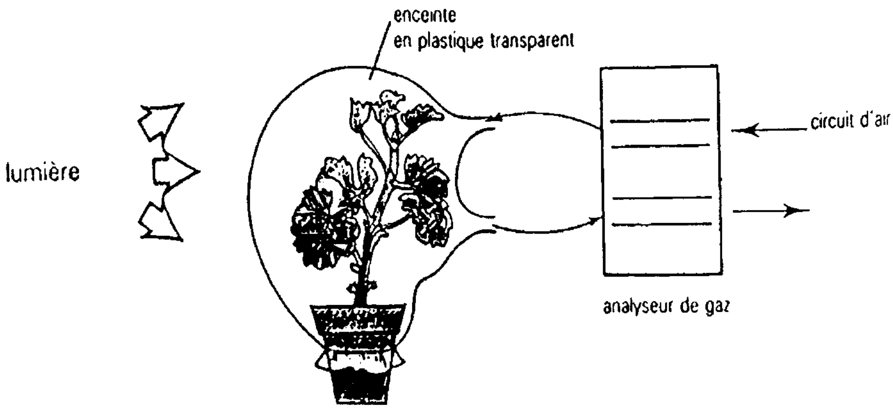


Document 5. Children-geared information.
– The adjective “delightful” is not part of the 8-10 year old children’s lexicon.
– The tooth brush is spotted by less than one child out of two.
– Bacteria are not identified by 75% of children.
– Worse most children even cannot identify the tooth.

EXAMPLE 3. Measuring gas photosyntetic exchanges.



Document 6. Graph of principle of the gaz photosynthetic exchange measure.



Document 7. Another graph of the principle of the gas photosynthetic exchange measure.
First of all, it can be said that despite a few symbolic differences the two graphs taken from different text books seem to represent the same experiment.
However a closer does not take into account of all sorts of gazes which might due to the numerous organisms of the soil, be emitted and disturb the composition of air within the cover. Little cause in the teaching materials great effects on the reasoning and rigorous, procedure which are characteristics of experimental action.

3.3. *Evaluation of evaluation tools*

If one goes beyond the good wishes expressed by official texts on the evaluation of learning in science in search of habits settled and the very practice of the different tests designers, one discovers that in the whole, the pathology of evaluation in sciences goes beyond the long-critised subjectivity of judgements passed by examiners. It is founded on its chronical lack of validity relative to the stated contents and objectives, validity being defined by the extent to which tests evaluate what they are supposed to evaluate.

In many countries, teaching is centred around acquired knowledge. The starting point is university knowledge already built up, then, a list of themes followed by a list of teaching contents which rank high on the programmes of the educational system.

In the case of achievement Evaluation in Sciences, when a categorisation by themes of topics suggested over a fairly long periods is carried out and compared to the prescribed programme, it can be noticed, that in most cases in practices, all the programme, it can be notices, that in most cases in practice, all the programme chapters are not given equal treatment.

This allows to find out that there is a sort of an implicit value scale according to which certain chapters are more frequent. Others occur from time to time while one category never appears. A times a clear cut discrimination between the different notions and concepts can be notices within the same chapter.

A systematic study of objectives from the questions usually asked in sciences tests shows that contrary to the state and documented desire to move science teaching towards experimental procedure and scientific attitudes

Questions that require the use of acquired knowledge are the most frequent, in spite of the misleading appearances of the different instructions used by designers in setting questions (Analyse, Interpret, Deduce).

In fact learners are asked to show what follows:

– specific knowledge

– mastery of one (or more) problem solving (strategy[ies]), type(s)

– (exceptionally) skills to analyse a situation under study (Johsua, 1983).

Let us take the example of the evaluation of the learners' skill to form hypothese. It is noticed that the existence of familiar laws whose demonstration has necessitated hypothese known to the learners after they have been taught in class does not leave much room to questions evaluating their skills to form their own hypothese.

Indeed, when learners are faced with such questions, they look back into the set of explanations they already known for those that can fit, as they are never asked to exclude any hypothesis, but to choose the best.

Ultimately, the whole issue is only related to constructed automatisms solely for the monitoring of knowledge in the frame word of a closed systems whose importance is nothing else than success at the exam (Johsua, 1983).

As for the affective objectives, they have not all been evaluated (it must be agreed that they are difficult to evaluate in the framework of a “pen and paper” test).

The consequences are that, after a certain time, the examination turns round typical questions which are the object of swotting such as the exam tasks of analysis, interpretation or even explanation will require declaratives or procedural knowledge transfer.

This is mainly explained by the fact that all the given exercises are put forward in the frameworks of a pen and paper test, which does not allow learners to face a real problem, that is a more or less new situation whose answer must be built up not retrieved automatically.

Moreover, in the countries where, for sometime, people have cherished the idea of making learners acquire, about the themes on the programmes, certain basic concepts and procedures from one or two examples, then to make them show during the evaluation what they have learnt though a transfer to a context not dealt with in class, have waken up from that dream.

It is noticed rather an insidious knowledge inflation phenomenon in the chapters focused on at the exam, as every time a new example came up at the tests, it was systematically swotted on the following year in class on teachers’ more initiative finally, overwhelmed by a mass of observations, subjects or definitions, most learners have no other solutions than learn as many of them as possible by heart. The sequence observation-memorization.

Monitoring and oversight becomes frequent practice instead of the opposite: observation-use of concepts-interpretation-relation with wider concepts-problem solving (Novak, 1970).

4. Conclusion

At the end of this analysis I think to have widely proved that it is quite possible and useful, and even urgent and compulsory to widen the evaluation field in the teaching of sciences to the differentes questions that underlie the evaluation issue and the need to make decisions only when fully informed widely claim for such expansion. The adoption and the practice of such a systemic vision in scientific teaching will without any doubt, allow to improve it qualitatively. This improvement is dependent up on the quality of it's the learning evaluation tools.

In the teaching of sciences, as it seems presently, achievement testing is more debatable than progress testing.

Indeed the pseudo-democratic centralism used to administer in a more transparent an fairer way the evaluation of objects resources does not permit, during the achievement test, to muster all the didactic available to the scientific disciplines in their every day teaching in every school institution, owing to the number of candidates and the limited time allowed to the exam.

To solve this problem of evaluation in the teaching of sciences it is desirable to remember that whatever the philosophy and the content of a syllabus, its actual efficiency is largely determined, after a number of years, by the exam format for which the teacher has to train his learners (Guinier, 1980).

I believe that, for a project aiming to encompass all the ground aspects of the evaluation in the teaching of sciences to be likely to get off the it is necessary to tackle the problem through teachers' initial and continuing training.

Indeed teachers' straight forward training in theoretical, but mainly practical and critical training is the challenge to meet for evaluation to occupy its rightful position in the teaching of sciences.

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STRATEGIES FOR THE IMPROVEMENT OF K-8 SCIENCE EDUCATION A REPORT FROM THE UNITED STATES

DOUGLAS M. LAPP

The National Science Resources Center (NSRC), operated jointly by the National Academy of Sciences and the Smithsonian Institution, works to improve the quality of science education in elementary and secondary schools. The NSRC advocates an inquiry-centered approach to science education that challenges students to expand their understanding of science concepts, skills, and attitudes through hands-on explorations. Through its science materials development, information dissemination, and leadership development programs, the NSRC assists science education reform efforts in school districts across the United States. Scientists and engineers from universities and industry, as well as teachers and school district leaders, collaborate in the development and implementation of NSRC programs.

Building on fifteen years of experience working to improve science education, the NSRC has developed a model to guide school districts that are seeking to establish an inquiry-centered science education program. The NSRC model involves five complementary elements that are needed to create and sustain an inquiry-centered science program:

I. *Research-Based Curriculum Materials*

Carefully crafted, comprehensive, inquiry-centered curriculum materials lie at the heart of an effective science education program. Such curriculum materials should be developed collaboratively by teachers and scientists, field tested with students, and carefully evaluated before being published. The learning materials must provide developmentally appropriate opportunities for children to expand their understanding of science concepts, acquire skills, and develop positive attitudes toward science. Lessons must challenge students with a variety of learning styles and give them opportunities to apply what they have learned to real-life situations. The lessons must also offer opportunities for teachers to integrate science learning with other areas of the curriculum.

II. *Professional Development*

Carefully designed professional development programs are needed to prepare teachers to teach inquiry-centered science. These professional development programs need to focus initially on helping teachers become familiar with fundamental science concepts, learn how to use inquiry-centered science materials, and develop effective classroom-management techniques. Later, attention can turn to helping teachers acquire in-depth science content knowledge, perfect an inquiry-centered approach to teaching and learning, develop appropriate methods for student assessment, and integrate science with other subject areas.

III. *Materials Support*

Students who engage in inquiry-centered science need a variety of science materials – from hand lenses to magnets to organisms. A materials support system is needed to ensure that science materials are ready for classroom use throughout the year. Materials support staff take charge of ordering new supplies, refurbishing science kits, and ensuring that they are delivered to teachers when needed. Centralizing these materials support functions for an entire school district can make materials support more efficient and cost effective.

IV. *Student and Program Assessment*

Inquiry-centered science requires teachers to use new assessment strategies. Pre-assessment activities to assess students' knowledge before beginning a learning sequence can provide information to help teachers plan learning activities. Additional assessments need to be integrated throughout the learning process to provide both teachers and students with a way to evaluate their progress. Final assessments should be designed to assess what students know and are able to do as a result of their inquiries.

In addition, periodic program assessments are needed to determine whether the science program is meeting its goals and to guide curriculum selection, professional development, and other activities.

V. *Administrative and Community Support*

Planning and implementing an inquiry-centered science program require the support of a broad range of stakeholders. These individuals should share a vision of what is needed to create an effective inquiry science program. Equally important is the need to establish an infrastructure that will support this shared vision.

To be effective, science education reform efforts needed to enlist the support of school and community leaders. A broad range of community organizations can become effectively involved in the reform of K-8 science education. They include colleges and university faculty, business and industry, museums, philanthropic foundations, parent-teacher organizations, and other educational organizations. Scientists, engineers, and corporate leaders can be especially effective in building support for science education reform. Scientists can also team with teachers to lead professional development programs and parents may volunteer time to help replenish science kits in science materials centers.

Working together, these individuals can form partnerships that will ensure a sustained commitment to science education reform.

* * *

The NSRC has developed a book and a videotape to assist those who are working to improve science education in the schools. *Science for All Children: A Guide to Improving Elementary Science Education in Your School District* provides concise and practical guidelines for bringing about science education reform. Designed for school leaders, scientists, teachers, and community leaders who are committed to improving science education for all children, the book and videotape explain the philosophy and research underlying inquiry-centered science teaching and describes in detail the five elements that are essential to science education reform. The book also proves information on how to organize, plan and implement a new science program. *Science for All Children* is available from the National Academy Press (Telephone 1-800-624-6242), or can be accessed online over the internet at http://www.nap.edu.

THE PLACE OF SCIENCES/TECHNOLOGIES IN THE EDUCATION OF TWENTY-FIRST CENTURY CITIZENS

THE COMPUTER IN THE SCHOOL: A TOOL FOR THE BRAIN

ANTONIO M. BATTRO

The information world in science education

The impact of the information world in science education begins in elementary school. When a child sends an electronic message to a friend he is using a set of powerful computer tools: word processing, dictionaries, machine translation, digital images, audio, etc. These are "new tools for the brain", that transmit and amplify many feelings, emotions and cognitions in a totally new way. These instruments can work as "intellectual prostheses" for our mind.

I would present a case that illustrates this view. It is related to the emotional impact of the terrorist attack of September 11th in New York and Washington, on Nico, a 11 year-old child living in a remote place from the terrible events. Nico, who is at school in Argentina in his 6th grade, sent the following e-mail in Spanish to his friend, a university professor in the United States:

> "Hola, soy Nico. quería decirte que siento mucho lo que pasó allá en Estados Unidos espero que si tenías parientes ahi en NY que no les halla pasado nada. me dan muchas ganas de volver a verte. te mando un beso grande y mi mamá tambien. NICO".

He did not use the spelling software in Spanish to find some errors in his message, but we can leave the English translation to a machine:

> "Hello, I am Nico. wanted *decirte* that I feel much what happened back in the United States I hope that if you had relatives *ahi* in NY that does not find last anything to them. they give many desire me to return to *verte*. I also send to a great kiss and my mother to you. NICO".

Machine translation, in spite of its current and evident limitations, can be used with great profit in schools – it inspires linguistic criticisms and lively discussions – and will continue to improve. Children enjoy using this powerful tool to check their own proficiency in a foreign language and love to engage the machine in “linguistic loops”, i.e. translating an expression from language A to B, and then the translated sentence B into A, and so on. My point is that we are dealing here with a message transmitted by the web that eliminates many practical obstacles such as writing the letter on a paper, addressing the envelop, looking for stamps, going to the post office, etc. Also the e-message has the advantage of reducing the affective distance between both partners, we can even talk of a “distance zero” between them. Moreover we can feel that this information technology is closing the gap between the child and the adult, and the novice and the expert, in a very profound sense.

Even more so because Nico is a hemispherectomized boy and he is using the computer as a “prosthesis”, he is hemiplegic and his writing by hand is impaired (Fig. 1). He was given a right hemispherectomy when he was three years old to control intractable epilepsy, and he is successfully performing in life since his surgery using only his left hemisphere. He has compensated his devastating loss and became a regular student at school and a remarkable example of rehabilitation (Battro, 2000).

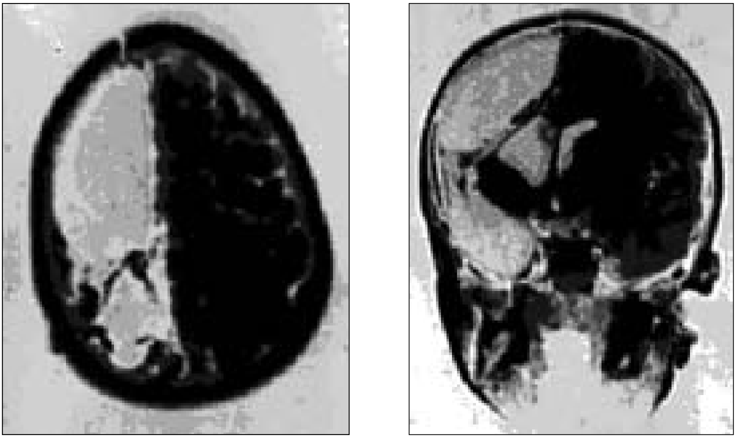

Figure 1. Two images of Nico’s brain showing the loss of the right hemisphere at the age of three.

Another related and striking example is Louis Pasteur. As one of his biographers stated: “Le lundi 19 octobre (1868), Pasteur, bien que souffrant d'un étrange malaise, d'un fourmillement dans tout le côté gauche, eu le vif désir d' aller présenter â l'Académie des Sciences, le travail d'un italien, Salimbeni". (Vallery-Radot, 1922). In the following hours "Pasteur suffered a cerebral hemorrhage on his right side... It has been said that after his injury (at the age of 46) 'he had only half a brain'. Nevertheless, after this injury, he did some of his best work" (Wiener, 1948).

These extreme cases of people working normally or being superbly creative in the sciences after the loss of a significant part of their cerebral cortex open, at least, two challenging questions: How much "brain power" do we need in order to learn and create knowledge? We have some 10^{12} neurons in our brain; how many do we actually use in a specific cognitive task? Perhaps this is not a quantitative but a qualitative problem related to the plasticity of our neuronal networks, of what is called "activity-dependent plasticity" (Sharma *et al.*, 2000). We also know that growth of the brain is closely related to growth of action and thought and that both brain activity and optimal cognitive functioning develop in fits and starts (Fischer and Rose, 1997). Modern education should take into account the results of neurocognitive research, and one task would be to understand the biopsychology of computing.

The click option and the cortical shift

Pasteur did not need a computer in order to make the remarkable discoveries that have improved our life, but one hundred years after his stroke children all over the world were starting to use the computer to calculate, to write and to draw, to make music and to control elementary robots and sensors (Papert, 1980). Many disabled persons also began to profit from and to enjoy the power of digital machines to learn and to work. Now the computer has conquered, definitely, its place in education. This is the result of many coincidences between the brain and the computer, which seems to bring an incredible expansion to our mental capacities. Everyone, for instance, can agree that the child has an astonishing talent to use a computer, even before he or she can read or write, but few have asked why this is so. This extraordinary matching of the child and the digital machine is both a gift of nature and of culture.

The biological reason is because our brains, and the brains of many animals, are naturally adapted to make "single-option decisions", by yes or no. In fact, ever since the nineteenth century experimental psychologists have intensively used the very simple device of a mechanical or electronic switch to study animal and human behavior. A simple click on a button can produce a cascade of effects in an experimental setting that can reinforce or inhibit a well-defined sequence of tasks. On the other hand, the computer is the cultural artifact that has led to the modern state of globalization of our society. The modern computer, with its flashing screen, its astonishing sound equipment, its keyboard and mouse, its modem, is the right instrument to make interesting things happen, in our own environment or at a distance, with a simple click. What we call the "click option" is only the final step of a *cognitive decision process*, which can be of great complexity. Think about the moment we decide to buy a book through the Internet, it is just a click at the end of a long search on the screen, browsing the digital shelves, reading excerpts and reviews, etc. All this search is part of a *digital heuristic* that belongs to the new *digital skills* developed by a citizen of our global society. Perhaps we are witnessing the unfolding of a kind of *digital intelligence* for the new digital culture of the twenty-first century.

Children of a very young age, even under a year (Bruner, 1883), can learn to make clicks on the computer and produce some significant results. The user's motivation is very high because of the immediate feedback; the answer is automatic and facilitates further exploration. It is a happy coincidence that contemporary technology has produced such a powerful tool that fits so well with children's interests. It would be difficult to imagine the conquest of our world by the computer without children's extraordinary capacity to play with it. A computer industry restricted only to adult experts would be unsustainable. As Nicholas Negroponte rightly says "each generation will become more digital than the preceding one" (Negroponte, 1997, p. 231). This cultural fact is substantial to our understanding of modern education, where, for the first time in history, the pupil may know more than the teacher does. In a sense, the mastering of the new digital field is very similar to the acquisition of a native language. No child needs to read a manual to use a computer or take grammar lessons to speak. Moreover, the computer is a machine that can simulate any particular machine; it is a tool of tools (Minsky, 1967). Equipped with the right interfaces the computer can perform multiple tasks. And this is one of the reasons why we need computers in education, in particular in the teaching of science. As I said before, the most elementary action with a computer is the "click option", wich every child uses with remarkable ease; even those who are severely disabled can learn to produce a click, if properly assisted by an expert (Rose and Meyer, 2000).

In my opinion the computer enables us to expand our brain-power because it might activate some brain areas that were not used to perform some specific tasks in a traditional pre-digital culture. Let us take an example: drawing by hand or drawing by computer. The skillful analogical movements of the arm, the hand and the fingers, which help to make a drawing: this is a very complex sensory-motor process that is controlled by specific areas of the cortex and the cerebellum. But the user can shift to a digital modality that by-passes hand-drawing: the machine will do the drawing and the user only the programming. In this case, the brain makes a "cortical shift" from the analogical task of drawing by hand to the digital task of producing a computer program as in Figure 2. We can also obtain interesting functional magnetic resonance images fMRI to monitor this cortical shift (figure 2, see page I).

Writing a computer program needs linguistic and logical skills, while drawing needs spatial skills, and we can perfectly separate the cortical areas and cognitive modules involved in language and in drawing (Gardner, 1983, 1999). The artist can even *dictate* the drawing procedure to the machine (with a voice recognition device) instead of writing it down on the keyboard (Battro, 1991). It is of great theoretical and educational importance to identify the different cortical areas that are involved in analogical and digital tasks. In the case of Nico, because of his right hemispherectomy both tasks take place in the left hemisphere. I understand this remarkable compensation following brain injury as a proof of *the expansion of the natural neural plasticity with the help of a computer.* The same neurobiological argument favours the use of computers in children in general: new digital tasks will require new digital skills and the exercise of new patterns of brain activation. This opens a new field in education which way be called *neuroeducation*.

We may have a glimpse of some future applications of neuroeducation in the paper published by Stanislas Dehaene and his colleagues (1998) concerned with arithmetic (number comparison). In this experiment, the (adult) subject pressed a key with the left or right thumb to decide whether digits presented visually were larger or smaller than 5. We know that the precentral right and left brain areas control, respectively, the left and right hands. This fact enables the experimenter to make very accurate inferences about the cognitive tasks performed by the subject by a kind of "reverse neurology" which predicts the behavior (the number comparison) from the (right or left) brain activation. As the authors say: "Once we understand the function of a given brain area or network of areas, it should be possible to use on-line activation measurements to infer what kind of task the subject was performing". This very interesting experiment opens many intriguing questions about the validity of what might be some day a "reverse education assessment", i.e. the evaluation of a given cognitive performance from the corresponding brain pattern produced during the task. To sum up, neuroeducation can be understood as a bridge – under construction – between the neurosciences and the sciences of education.

The dual world (real/virtual) of science education

We are living in a dual world, where many things have a double representation: the newspapers are printed on paper, and, at the same time, are published in the Internet; a molecule is produced in the laboratory and is simulated in the virtual space; a museum has real visitors but also as many, or more, virtual visitors on the web; a surgeon performs a hemispherectomy but also can simulate it by virtual surgery, etc. As a result, many human activities can be projected in two dimensions, real and virtual; the result is a path on a 2D cognitive space defined by these two orthogonal coordinates. Many people believe that the virtual is taking the place of the real, but this is a misunderstanding. It is just another, independent, dimension of our world. What happens is that the virtual dimension of journalism, chemistry, the visual arts, medicine, etc, is acquiring increasing relevance in our cognitive world. This is why the use of digital devices, of computer hardware and software, is also of increasing importance in education in general and in science education in particular.

The interaction with a computer enhances the child's cognitive field: learning to read hypertexts enriches the mental process with new perceptual modalities and new links, programming a robot develops new skills, simulations and animations open new windows to imagination and action (Resnick *et al.*, 2000). The enlarged (digital) educational field is, certainly, changing science education. In a celebrated paper entitled 'Unlearning Aristotelian Physics', Andrea diSessa (diSessa, 1981) used a computer to provide new insights about the notion of force. He programmed a dynamic object that could be directed to a target using very simple commands on the computer, such as Kick, Right and Left. The game was to hit the target with a minimum speed, like a landing on the Moon (Abelson and diSessa, 1981; Battro, 1986). Many children and young adults were tested and most of them failed in an "Aristotelian manner", because they used the intuitive strategy: aim and shoot. They rotate the moving missile towards the target and then a Kick was given following the common intuition that "objects move in the direction you push them", i.e. that force correlates with changes in position. This is what diSessa calls now a *phenomenological primitive* or *p-prim* (diSessa and Sherin, 1998). The result is that the missile makes an "Aristotelian corner" and continues its movement without hitting the target. Only a few students applied the Newtonian idea that force correlates with changes of velocity (F=ma) and one of the preferred strategies (a "Newtonian corner") was to produce a turn and a Kick to stop the missile, then turn again and Kick to finish.

The important point is that the new brain imaging techniques can be used to test some cognitive changes produced by current education. For instance we can study the changes from Aristotelian to Newtonian performances in the subject's brain in the same way we can analyze the different cortical processes in reading strategies in English and Italian (Paulesu, *et al.*, 2000). We are moving from the general notion of "embodiments of mind" (McCulloch, 1968) to the study of specific "embrainments of science", a new task for the twenty-first century.

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