The Challenges for Science. Education for the Twenty-First Century
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# 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

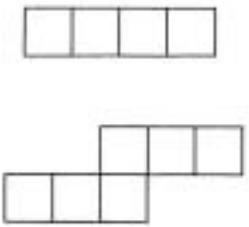
Latin word "con-capere"), that is, to grasp the universal in the particular. Each and every human word is a proof, including words uttered by professors of education who do not want to come clean on the issue as to what they take human beings for. And since they dissimulate, they would deserve to be 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.**

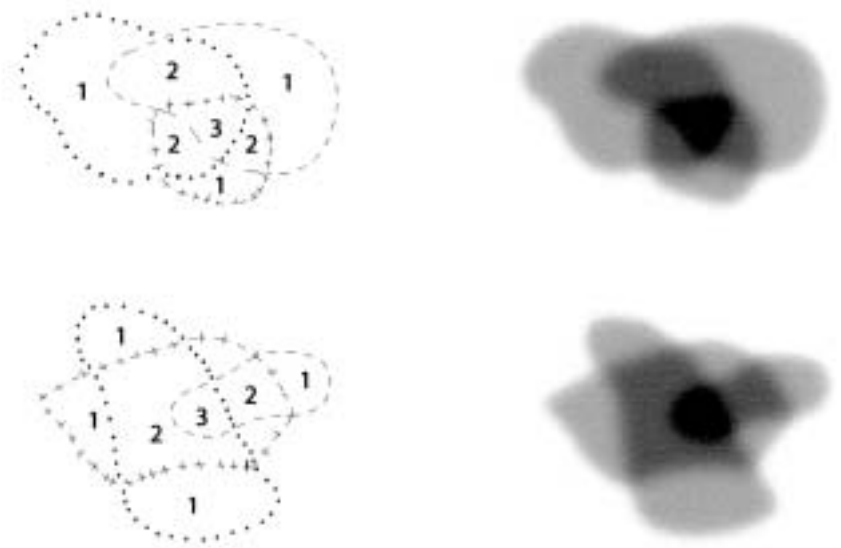



Figure 1.

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 nonlinear 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.