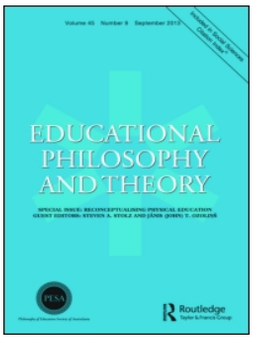

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Whitehead and science education.

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> Science is taking on a new aspect which is neither purely physical, nor purely biological. It is becoming the study of organisms. Biology is the study of larger organisms; whereas physics is the study of the smaller organisms (Whitehead 1933, 129).
>
> The first thing that a teacher has to do when he enters the class-room is to make his class glad to be there (Whitehead 1947, 171).

Alfred North Whitehead's theory of education is explicitly stated in 160 pages of one book *The Aims of Education* published first in 1929 and in six essays in his *Essays in Science and Philosophy* (Whitehead 1947, 151-224). *The Aims of Education* was for the most part addressed to school children in England. The six essays were more generally directed. However, most, if not all, of Whitehead's books have profound implications for education and particularly for the teaching of science. Whitehead believed that science had taken on a strictly mechanistic or substantialist stance in modern times. He called for a "more subtle science" (Whitehead 1933, 229) in which the organismic model would replace the strictly mechanistic one as suggested in the quotation at the head of this essay. The new vision would bring back to the teaching of science a new zest and inspiration.

Whitehead's vision of research and teaching in science is considered below in terms of a number of cardinal principles or axioms and in terms of a number of fallacies to be recognized and avoided. In discussing these I shall not confine myself to Whitehead's concepts alone but to interpreters of the Whiteheadian school of thought which has become known as process thought.

Four central axioms:

1. The principle of organic mechanism

Any teacher of science eventually conveys his or her answer to the question - what is nature made of? The answer may not be explicit, but it is certainly implicit in any science course. The dominant answer today is given in terms of the mechanistic model of nature. The universe is seen as a gigantic machine made up of countless smaller machines, be they protons or people. The image goes back to the Greeks, but it was given its most complete expression in the 16th and 17th centuries with the rise of modern science. A distinction is to be made between methodological mechanism and metaphysical mechanism. In methodological mechanism the entity is investigated as if it were a machine. Metaphysical mechanism goes further and says the entity, be it an electron or a human being, is a machine - though one does not logically follow from the other. As a methodology, mechanism has been highly successful. We got to the moon on Newton's mechanistic laws. The triumphs

of molecular biology are triumphs of the mechanistic methodology. There are mechanical aspects of living organisms. Limbs operate as levers. The heart operates as a pump. And there are some biologists who believe that the brain is to be understood as a computer, though as yet that analogy has not been particularly helpful in investigating brains. Whitehead (1938, 154) recognized that in one sense the mechanistic abstraction had been, for about ten generations, a happy one in that it had allowed the simplest things to be considered first. This judgement is echoed by Levins and Lewontin (1985, 2-3).

> The great success of Cartesian (mechanistic) method and the Cartesian view of nature is in part a result of an historical path of least resistance. Those problems that yield to the attack are pursued most vigorously, precisely because the method works there [but at the cost that] other problems and other phenomena are left behind, walled off from understanding by the commitment to Cartesianism.

In particular, phenomena which are walled off by a strictly mechanistic methodology are the very small in physics and the nature of mind and consciousness in living organisms. The mechanistic methodology is reductionist. It consists in dividing the world into its smallest components. Having divided the world into its smallest bits you then try to build it up again from those bits, and of course when you do that you must get a machine. The next step is to say that the universe and all that is in it are machines. That is a metaphysical statement. The essence of metaphysical mechanism is the proposition that a thing consists of the sum of its parts, and that the parts remain unchanged no matter what particular whole they constitute, be it a star or a human brain. Newton's system of the universe, as it has been handed down to us, is mechanistic. Both the smallest and the largest objects obey identical laws. The universe is seen to be composed of bits of inert matter moving through space according to deterministic laws. In the Newtonian universe, once the initial conditions and the laws of force are given, everything is interpreted in terms of the mechanical movements of atoms and molecules, and all is calculable for every after. Whilst the elements of this view come from Newton, he himself was not a Newtonian. His views of matter were much more complex and in many ways more organic than mechanical. It was later workers, particularly the Dutch astronomer Huygens and the engineer, philosopher and biologist, Descartes, who developed the mechanistic model of the universe.

As a methodology, mechanism has its limitations which have been recognized in quantum physics and by some students of living organisms. As a metaphysic, mechanism lets us down in one major respect. As Whitehead (1933, 69) put it, "Nature is a dull affair, soundless, scentless, colourless; merely the hurrying of material, endlessly, meaninglessly". There is an enormous gap between what natural science describes and what we experience as living, sensing, experiencing human beings. In his famous chapter "The Romantic Reaction" in *Science and the Modern World* (1933) Whitehead points to the English poets who reacted against the mechanical universe. Wordsworth felt something of immense importance had been left out. What had been left out comprised everything that was important for him. His criticism is summed up in one line that might well be written over the portals of every laboratory - "We murder to dissect" from "The Tables Turned".

> Sweet is the lore which Nature brings;
> Our meddling intellect
> Mis-shapes the beauteous form of things;
> We murder to dissect.

This criticism which is central in Whitehead's *Science and the Modern World* is echoed by modern writers who see science as reifying nature. As Merchant (1980) puts it "As the sixteenth-century organic cosmos was transformed into the seventeenth-century mechanistic universe, its life and vitality were sacrificed for a world filled with dead and passive matter". This constituted what she calls "the death of nature". "The resultant corpse was a mechanical system of dead corpuscles, set in motion by the Creator, so that each obeyed the laws of inertia and moved only by external contact with another moving body" (Merchant 1980, 195).

Whitehead (1933, 99) provided an alternative to strict mechanism in what he called organic mechanism or the theory of organism. Because of the emphasis on relations rather than substances, Birch and Cobb (1981) refer to it as the ecological model of nature. The living organism, with all its senses and feelings complete, becomes the model of all of nature. Or as Cobb and Griffin (1976, 13) put it "human experience [is seen] as a high-level exemplification of reality in general". The mechanistic model puts the emphasis on substances that obey mechanical laws. The theory of organism puts the emphasis elsewhere - on relationships. Moreover, the relationships are not between substances but between events. This model differs from the mechanistic model in two important respects. There are no substances. And there are two sorts of relationship. Descartes defined substance quite precisely: "And when we conceive of substance, we merely conceive an existent thing which requires nothing but itself in order to exist" (quoted by Whitehead 1930, 92). And as Whitehead says (94) there is no entity which requires nothing but itself in order to exist. There are no substances. The misconception which has

haunted philosophic literature throughout the centuries is, says Whitehead (1941, 687), the notion of "independent existence". "There is no such mode of existence; every entity is only to be understood in terms of the way in which it is interwoven with the rest of the universe". This is now generally accepted in quantum physics. In so far as the quantum physicist uses the word "particle", it is no longer conceived as substance. H. Stapp has expressed the quantum concept of "particle" thus: "An elementary particle is not an independently existing unanalysable entity. It is, in essence, a set of relationships that reach outwards to other things" (quoted by Davies 1984, 49).

There are, in Whitehead's view, two sorts of relations. There are external relations that push and pull, as exemplified in Newton's laws of motion. And there are internal relations that we recognize in our inner feelings as part of our intrinsic nature. Whitehead carries the notion of internal relation right down to the so called ultimate particles. The idea of an internal relation is of a relation which is constitutive of the character and even the existence of something. Such a relation cannot characterize a substance because substance is defined in terms of independent existence. The internal relations of an entity depend upon its environment. My own being as a person is dependent upon the particular internal relations I have experienced with friends and those who have modeled me. So too with other entities. As Whitehead (1933, 99) said, "an electron within a living body is different from an electron outside it, by reason of the plan of the body. The electron blindly runs, either within or without the body; but it runs within the body in accordance with its character within the body. And this plan includes the mental state. But the principle of modification is perfectly general throughout nature, and represents no property peculiar to living bodies".

Since Descartes, people lost sight of internal relations and came to think of external relations as self-sufficient. The new physics or quantum physics restores a more complete perspective which brings with it a sense of the wholeness of things. It deals with entities that truly evolve in cosmic evolution and are not simply rearranged like the nuts and bolts in a machine can be rearranged. It is a view that Whitehead (1933, 134) saw logically required by any serious doctrine of organic evolution. "A thoroughgoing evolutionary philosophy is inconsistent with materialism. The aboriginal stuff, or material, from which a materialistic philosophy starts is incapable of evolution... Evolution, on the materialist theory, is reduced to the role of being another word for the description of changes of external relations between portions of matter. There is nothing to evolve, because one set of external relations is as good as any other set of external relations. There can be merely change, purposeless and unprogressive... the doctrine thus cries aloud for a conception of organism as fundamental for nature". Evolution, according to the organic model, is the evolution, not of substances, but of subjects that are transformed as they evolve. The critical thing that happens in evolution is change in internal relations of subjects.

2. The principle of interpreting the higher in terms of the lower

The organismic model of nature espouses the principle of interpreting the lower levels of organization in terms of the higher, as well as vice-versa. It is therefore post-reductionist. In reductionism all causation goes from the bottom up. Everything complex is to be interpreted by reducing it to its most elementary constituents. In biology that means interpreting development, physiology and behaviour, for example, in terms of the behaviour of molecules and eventually of the components of molecules.

Quantum physicist John A. Wheeler has asked rhetorically: "Here is a man so what must the universe be?" The proposition is that we cannot understand what atoms or electrons are until we know what happens when they are organized into human brains. No analyses of atoms in mud will lead us to suppose that in brains they result in thought and consciousness. The fact that atoms in brains result in thought and consciousness tell us something about atoms we can find from no other source. Hence the Whiteheadian principle that an atom or an electron in a brain is different from an atom or an electron not in a brain. We know what a thing is by what it becomes in all its manifestations, not simply its manifestations at the most elemental level of organization. It is patently absurd to suppose that the human can be understood in terms of what atoms and molecules do in test tubes. Reductionist science breaks down when attempts are made to apply it to the exclusion of all else in understanding the human. Science then becomes a tyranny as in behaviourist psychology and sociology.

3. The principle of the unity of nature

Whitehead wrote much in criticism of the "bifurcation of nature" into matter and mind or nature and God. He called for a more holistic view of things. The world is not made up of two sorts of things, stuff and minds. When mind and matter are separated as they are in dualism they can never be put together again at any level. For Whitehead, mind and matter are two aspects of the one thing. His holism is therefore not the unity of physicalism but of psychicalism. Mind is a part of nature at all levels of organization, though the meaning of mind at the electron level is, of course, different from that at the human level. Nevertheless words such as sentience, feeling and mind are relevant all the way down the line.

This is, for some people, the most difficult concept of all to grasp This is partly because they try to visualize thinking electrons. Electrons don't think. The proposition of psychicalism is that there is no point in cosmic evolution when mind appeared for the first time. It was there from the beginning. Matter and mind are like the two poles of a magnet. They cannot be separated at any level of organization. This of course overcomes the problem of the dualist who tries to derive mind from matter and pin-point when it first appeared. [For a further discussion of this see Birch and Cobb (1981, 71; 98 - 109).]

4. The principle that knowledge is one and indivisible

The dominant model of knowledge is that it can be divided into compartments called disciplines such as physics, economics, religion and so on. The idea of a discipline is that the information in it is relatively independent of that in other disciplines. So universities are built up of a multitude of departments, each dealing with a different discipline. We suppose that knowledge is like a huge jig-saw puzzle. The bits and pieces are the bits of knowledge that the disciplines give us. But when we try to fit them together they do not fit. They do not make a complete picture at all. This is what happens when we opt for the substantialist (substance) prejudice in the field of knowledge. Knowledge is not a substance. It cannot be subdivided into separate compartments without losing something essential - the unity which no segment can grasp This is precisely the intellectual dilemma so powerfully symbolized in the parable of the Tower of Babel. The fate of the Tower of Babel represents the human intellectual predicament. "We seem to be compelled to shape facts and data, as we know them", says Koestler (1982, 685) "into hard bricks, and stick them together with the slime of our theories and beliefs. And thus we continue to carry bricks to Babel".

Today we have a crisis of knowledge. It is not simply that knowledge doubles about every decade. The crisis is not a crisis of quantity. It is a crisis of experts. Not only do the experts from different disciplines fail to understand one another but the experts within disciplines also disagree. Heidegger said "science does not think" by which he meant that people trained in science are not trained to cross disciplines. They are trained to think only within a very narrow field and that gives them tunnel vision. To think is to cross boundaries.

The fragmentation of knowledge has far reaching implications. For example, Whitehead (1968, 131) deplores "the increasing departmentalization of universities during the last hundred years, (which) however necessary for administrative purposes, tends to trivialize the mentality of the teaching profession". The fragmentation of knowledge has given rise to destructive conflict between individuals, disciplines, ideologies and nations. It has helped to plunge the world into its present global crisis of management. The problems of global management are all connected. You can no longer do only one thing. Resource shortages, unemployment, inflation, environmental deterioration, the population explosion and even crime are all interconnected. This network of problems will not be solved by any one expert or any number of experts. It is one problem and has to be tackled as one.

Experts provide us with a wealth of information. They load the table with countless pieces of a jig-saw puzzle. How to put them together when they don't fit? That's the problem. Hence T.S. Eliot's questioning in Choruses from "The Rock":

> Where is the life we have lost in the living,
> Where is the wisdom we have lost in knowledge,
> Where is the knowledge we have lost in information?

Addressing school children, Whitehead (1949, 18) said, "There is only one subject-matter for education and that is life in all its manifestations". He went on to illustrate how we offer instead a collection of subjects from each of which nothing in particular follows. Whitehead considered that one of the devastating divisions was that between science and religion. "It is fashionable" said Whitehead (1942, 53) "to state that religion and science can never clash because they deal with different topics. I believe that this solution is entirely mistaken. In this world at least you cannot tear apart minds and bodies". So important is the healing of the rift between science and religion that Whitehead (1933, 224) said, "When we consider what religion is for mankind, and what science is, it is no exaggeration to say that the future course of history depends upon the decision of this generation as to the relations between them". As a result of artificial territorial claims of science and religion both are impoverished There are wider truths and broader perspectives to be explored in a post-modern world view. That will require "a deeper religion and a more subtle science" (Whitehead 1933, 229). To some extent the followers of Whitehead have been seeking such an understanding as, for example, the many consultations promoted by the Center for Process Studies in California between leaders in different disciplines, resulting in publications such as Cobb and Griffin's (1977) *Mind in Nature*. What has been blocking the creative relationship between science and religion has been the substantialist paradigm. As soon as scientists break out of that, religious questions are asked. The domain of concern widens as we see in the writings of physicist David Bohm and biologists C.D. Waddington and Sewall Wright (in Ayala and Dobzhansky 1974).

Whitehead and science education

Five fallacies of the mechanistic view

Whitehead and his followers have been quite explicit in exposing fallacies of the mechanistic or substantialist world view that are usually unrecognized or ignored by those who practise and teach science.

1. The fallacy of misplaced concreteness

This fallacy enunciated by Whitehead (1933, 64, 72) is to identify an abstraction with the concrete or real. To say that the human being has some machine-like qualities is correct. To say the human is a machine is to commit the fallacy of misplaced concreteness. Besides having bones and tendons that operate as levers and a heart that has pump-like properties, a human being experiences and has feelings. Machines don't. To reduce a particular sort of behaviour, such as aggressiveness, to the laws of mechanics is to reify or "thingify" nature. It is the fallacy inherent in the sociobiology which attempts to bring social behaviour into the realm of the predictive and quantitative by reducing all behaviour to the effects of genes. The fallacy has terrible consequences when it leads us to treat humans and other animals as machines, that is to say as objects and not subjects. The fallacy also leads to a mechanistic view of the world as a whole.

A variant of the fallacy of misplaced concreteness is the so-called "naturalistic fallacy". It is the fallacy of trying to derive human "ought" from what "is" in the non-human world. It is a fact that in nature there is a "struggle for existence". Of all the individual plants and animals that are born into the world, very few survive to maturity. Some people argue that since the "struggle for existence" is a fact of nature it must be right for humans too. This is the basis for Social Darwinism. This argument was used by Mussolini to justify his invasion of Abyssinia. The fallacy is the supposition that ideas of justice can be derived from the jungle. The history of humanity is, in part, a history of human victories over nature, of disease being eradicated and mountains being moved. Nature, in some of its aspects, may be "red in tooth and claw" as Tennyson said. But that is no reason for humans to pursue the course of aggression. To be civilized is to do the opposite. The naturalistic fallacy consists in equating a mere aspect of nature with the whole of life.

The term "naturalistic fallacy" is unfortunate as it gives the impression of a division between the natural and the human. It is a fallacy of the modern world-view to make such a division. It is not a case of the non-human being natural and of human beings being non-natural. What is, is natural.

2. The prosaic fallacy

This is refusal to attribute feeling to things that feel (Hartshorne 1977, 95). The world is not as tame as our sluggish convention-ridden imaginations imply. The most important thing about us is that we have feelings. That is how I know that I am. Descartes knew that when he said "I feel, therefore I am". It is a mistranslation to quote him as saying "I think, therefore I am". Feeling is more fundamental than thinking! This we may accept about ourselves. But what about non-human nature? We have little difficulty in believing that our pet cat or dog feels. They seem like us. Where to draw the line between feeling and non-feeling entities? The Whiteheadian answer is that there is no line to be drawn. When Whitehead refers to feeling he is not simply referring to perceptions by sense organs. Even human perceptions are not bounded by the five senses. We perceive more than sense can discover. And for non-human natural entities the word "feeling" is used in the sense of sentience, of being a subject as well as an object. Not every object has sentience. Some, such as stones and chairs, are aggregates of natural entities (molecules, atoms etc.). Whiteheadian panpsychism does not argue that all things are, or have, minds but that all things are themselves feeling entities or are composed of feeling entities. There is a distinction, in other words, to be made between a "compound individual" (an atom or a human), which has a unified feeling, and a mere aggregate (a stone or an automobile) which does not. The physicalist has the problem of explaining away the positive things - our feelings. The panpsychist has the problem of explaining away the negative - the outward lack of feelings in a stone. The panpsychist's problem, it seems to me, is much easier to resolve. There are at least four reasons for thinking that aggregates, such as stones and chairs, are devoid of mind and feeling (see Hartshorne 1977, 91).

The attribution of feelings to things that don't feel, such as rocks and chairs, is the pathetic fallacy (Hartshorne 1977, 95). This is a form of animism which is the besetting sin of a variety of the more mystical environmental movements.

3. The dogmatic fallacy

Whoever thinks at all tends to tie his or her thoughts together in some implicit system, however vague or simple that might be. Those who think more profoundly may be more explicit about the system that holds their thoughts together. Progress in thinking is largely the result of discordance of completing systems of thought. Whitehead (1942, 171) points out that the history of European thought to the present has been tainted by a fatal misunderstanding which he calls the dogmatic fallacy. The error consists in supposing that we can

produce notions about complex issues that are adequately defined, whereas in truth we see though a glass darkly. In medieval times theologians were the chief offenders in respect of the dogmatic fallacy. During the last three centuries their bad pre-eminence in this habit has passed to scientists. This is surprising in view of the history of science which witnesses the successive collapse of dogmas.

The fallacy of misplaced concreteness leads to making dogmas out of abstractions. A modern example is the idea that a natural entity is a machine whose reality and behaviour are in principle wholly specifiable in quantitative and mechanistic terms. Any suggestion that a natural entity might be an organism with qualitative and unpredictable features is dogmatically rejected. All this is not to say that we should not have convictions. On the contrary, these we must have. But we should be ready to let them be challenged from any source. "There is", said Whitehead (1933, 20) "a nemesis which waits upon those who deliberately avoid avenues of knowledge. Oliver Cromwell's cry echoes down the ages: "My brethren, by the bowels of Christ I beseech you, bethink you that you may be mistaken". The apathy of some people is a dogmatic slumber from which they need to be awakened to an intellectual rebirth. Hence the cynical remark that the best measure of a scientist's influence is how long he can hold up progress in his own discipline. "May God keep us", said William Blake, "from single vision and Newton's sleep".

4. The fallacy of the perfect dictionary

This fallacy holds that language in single words or phrases expresses accurately the fundamental ideas of philosophy, science, religion or of any other complex discipline (Whitehead 1966, 173). "Exactness is a fake". These words conclude one of the last of Whitehead's public utterances. They were said in the context of philosophical generalization that requires an imaginative penetration that goes beyond any too-precise pinning-down (Whitehead 1941, 700). There are fuzzy edges to understanding of complex issues. Sometimes our reach exceeds our grasp. Words fail to express what we think we know. There are two essential aspects to scientific understanding. One is imagination. The other is criticism. Without imagination there is no science. But not all ideas are equally worthy of attention. The scholar has to bring imagination, criticism and observation together in ideas that are expressed accurately, yet not too neatly tied up into final bundles.

Today countless sects and movements compete for our attention with simplistic phrases purporting to provide solutions to all the problems of life. Scientists too are guilty when, for example, in their debates with creationists they speak as if genetic variation plus natural selection provide an adequate solution to the mysteries of life. It is as well to remember American essayist H.L. Mencken when he said, "To every human problem there is a solution that is simple, neat and wrong!"

5. The fallacy of objectivity

This is the notion that science is objective in the sense that subjectivity does not enter into the scientific analysis. While Whitehead did not say so in as many words his position denies this. Any issue in science that is at all complex can be interpreted in a number of ways. Which side of the explanation one comes down on is a matter of subjective judgement. A good scientist, as compared with an average (mediocre) one, is more often correct in assessment of the facts as he or she knows them. But what are facts? Often there is no agreement on what the facts are. This is irksome for politicians and the public who want to know if nuclear power is safe. What we choose to call a fact is strongly conditioned by our interests and biases. Whoever said "You can't argue with facts" cannot have been reading the newspapers or for that matter scientific journals. Let us assume that we could, for any particular problem, amass all the pertinent facts and work through these difficulties. What then? No mere accumulation of facts can tell us how to decide on the definition of clinical death, or whether a human foetus is a human being or whether aversion therapy for homosexuals is good. All such decisions involve more than facts. They involve assessment of uncertainties and values.

It is rare to have a discussion on ethical issues in science without someone saying "That's not a fact but a mere value judgement" as though it cannot be a fact that Hitler was a bad man. Value-laden facts enter the domain of science as well as of ethics. This becomes patently clear when consultations are called to bring together scientists and ethicists on such issues as nuclear power or genetic engineering. It is never a matter of scientists putting their facts on the table and having them shuffled around by ethicists, according to the rules of the game. Good decision-making requires access to pertinent information, a recognition that facts are not value-free, a human sensitivity to values, common sense and uncommon sensibilities, private evaluation and public discussion.

The failure of science and technology to bestow values on the facts with which they deal contributes to a worldwide malaise or sense of meaninglessness. Our technological rationality is letting us down. The loudest advocates for creationism, as opposed to evolution, in the USA are not from uneducated backgrounds. They are middle-class citizens who are technically trained and have a smattering of biology that has been taught to them

dogmatically. Fundamentalist religious beliefs tend to flourish in those parts of the USA that have recently become centres of high-tech industries such as in Southern California and Texas (Nelkin 1977). The people who work in these industries feel let down by the image of the world their technology gives them. And so they are.

The fallacy of objectivity leads to technological optimism with its proclamation "Science will solve it". But our most pressing problems involve values and purposes. We need to be more than technological experts. The ultimate issue in education is not the multiplication of ever more specialized skills, important though they be. It is how the interests and vitality of life can be integrated into some sort of meaningful purpose and effort. The "is" of human life and the "ought" are bound together. One wonders how much longer scientific investigation and technology can survive without a more fully developed conscience on the part of scientists. We need a fundamental change in the mind set of teachers of science at all levels (see Gosling and Musschenga 1985).

Putting the model into practice

It is one thing to call for a science and its teaching that is organic, ecological and relational rather than mechanistic and compositional. It is quite another to put it into practice. The area of science in which the change in this respect is most evident is quantum physics which, as I have already indicated, has moved away from substance thinking to relational and event thinking. Some of the best books seeking to educate the public in science are in this new physics (Davies 1983, 1984; Pagels 1984). Any such trend in the biological science is less obvious. Biology is still very largely committed to the mechanistic model. The conclusions of a reductionist and mechanistic biology are dependent upon the assumption that the ultimate particles are exclusively mechanical in their properties. "Therefore", says Bohm (1969, 29), "the question of whether the basic laws of physics are in fact mechanical or not is of the utmost importance in biology.... It seems odd therefore (34) that just when physics is moving away from mechanism, biology and psychology are moving closer to it. If this trend continues, it may well be that scientists will be regarding living and intelligent beings as mechanical, while they suppose that inanimate matter is too complex and subtle to fit into the limited categories of mechanism". But, as Bohm points out, such a proposition cannot stand up to critical analysis, for the molecules studied by biologists in living organisms are constituted of electrons, protons and other such particles, from which it must follow that they too are capable of behaving in ways that cannot be described in terms of mechanical concepts. Now it is interesting that molecular biology which was the last into mechanistic biology may be the first out. The reason for saying this is that in describing actions of genes, molecular biologists now speak in terms of the "probability" of this pathway being "chosen" rather than that one. Absolute determinism is out even though the difference may appear small. Yet the difference between 99.9 per cent determinism and 100 per cent determinism is all the difference in the world. It opens up the possibility of a degree of self-determination and therefore of freedom (Prigogine and Stengers 1984). But it is not only in molecular biology that we can see some signposts of change. Sperry (1983, 1983b) and Pribram (1977) have produced models of brain function that are far more ecological than the strictly mechanistic models of most brain physiologists. Students of animal behaviour are moving in the direction of recognizing that the intrinsic nature of the animals they study has eluded them in the past. So they are now attempting to enter more into the mind of the animal (Griffin 1976, 1984). Jane Goodall (1971, 1986) has succeeded in doing that remarkably with chimpanzees by establishing a rapport with them in the wild. It seems that they returned the compliment. A mechanistic sociobiologist argues that individual human limitations imposed by genes place constraints on society. The non-mechanistic student of societies argues that social organizations are able to negate individual limitations. Lewontin (1983, 37) makes the analogy of human beings and flight. No human beings can fly by flapping their arms and legs. Yet we do fly because of the existence of aircraft, pilots, fuel production, radios - all products of social organization. Moreover, it is not society that flies, but the individuals who have acquired this property as a consequence of socialization. The individual can only be understood in terms of the total environment.

The geneticist no longer teaches "particulate genetics". There was a time when geneticists talked about genes as particles on chromosomes. The metaphor no longer holds up. What a gene is depends upon neighbouring genes on the same and on different chromosomes and on other aspects of its environment in the cell. The gene (DNA) does nothing by itself. It does not even make more DNA. It depends on enzymes in the cell to do these things. So the gene is no longer a substance in the Cartesian sense any more than an atom or an electron is a substance. We should be teaching that there are no particles in the strict meaning of the word, either in physics or in biology!

Modern evolutionary biology has been conceived and taught in a strictly mechanistic mould. For example, Monod (1974) interpreted all evolution in terms of chance and necessity. He contrasts his position with those who sought to find in every detail of nature evidence of deterministic design. The choice he gives us is

chance or determinism. Yet there is another possibility and that is chance and purpose. The process thinker Charles Hartshorne has developed this third possibility more than anyone else. Hartshorne (1984, 69) hits the nail on the head when he says "Neither pure chance nor the pure absence of chance can explain the world ... there must be something positive limiting chance and something more than mere matter in matter, or Darwinism fails to explain life". I have not encountered this point of view being offered in textbooks of evolution. That is not because it has been disproved. It has simply been ignored by evolutionists except for a few notables such as Waddington (1969) and Wright (1964).

In my experience students who have made some study of the philosophy of science raise questions about mechanistic science, which others don't. This happens even though their study may have paid little attention to non-mechanistic philosophies of science. We are intent on teaching more and more subjects containing more and more facts. Yet education does not consist in filling the mind with facts. What matters is the context of facts. Whitehead (1947, 171) wrote of the doctrine of enjoyment in education in which the student is led to the water that he wants to drink and enjoy. It is a process akin to the literal meaning of the word "education" which is to lead out by genial encouragement. This is the first of Whitehead's stages of learning, the phase of romance. The second stage of learning is precision in which concrete facts are dealt with and skills are acquired. But the paradox which wrecks so much education is, as Whitehead (1978, 338) remarks, "that the training which produces skill is so apt to stifle imaginative zest. Skill demands repetition, and imaginative zest is tinged with impulse. Up to a certain point each gain in skill opens new paths for the imagination. But in each individual formal training has its limits of usefulness. Beyond that limit there is degeneration". The third stage is generalization. Whitehead believed that the justification for a university is "that it preserves the connection between knowledge and the zest for life, by uniting the young and the old in the imaginative consideration of learning" (Whitehead 1929, 97). Whitehead was asked "Which are more important, facts or ideas?" He reflected a while and then said: "Ideas about facts" (Price 1954, 337). Whitehead (1947, 223) spoke of a tidal law in the emphasis of epoches," At low tide factors are studied in isolation. There is progress with manageable problems. The issue is trivialization; for meaning evaporates". And elsewhere Whitehead (1930, 117) wrote "progress in truth - truth of science and truth of religion - is mainly a progress in the framing of concepts, in discarding artificial abstractions or partial metaphors, and in evolving notions which strike more deeply into the root of reality".

Whitehead's three stages of learning, romance, precision and generalization, are considered in some detail from the point of view of a teacher of philosophy by Brumbaugh (1982). His chapters six and seven are concerned with an educational programme on precision. Much of chapter 8 deals with the stage of romance or motivation in which he takes as models two of Plato's dialogues, the *Meno* and *Lysis*. These illustrate in an exciting way the role of Socratic dialogue in leading out understanding with his pupils. In chapters nine and ten he concentrates on the stage of generalization. It would be a worthy project for someone to examine science education from these standpoints.

From all of Whitehead's writings one is left with the conviction that the role of education is to deal with facts and ideas in such a way that we are left with a generalized understanding in which many of the facts are no longer important. They are swallowed up in understanding. The extent to which we succeed in that could be a measure of our success in science education.

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