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ABSTRACT

Western culture's sense of reality has been shaped to a large extent by a mechanistic science world view. Such a viewpoint still dominates the thinking promoted by school science. Quantum theory is the most successful physical theory that has been conceptualized, yet Newtonian thought is still one of the main pillars on which the present-day curriculum is based. At the same time, educational theories regarding science teaching have largely been based on out-moded eighteenth century conceptions of the physical universe. Since a primary goal of science education is the development of a "scientific world view," the challenge for 21st century science education lies in devising an educational theory that incorporates understandings achieved in quantum physics. At the very least this involves posing a scientific world view that has not permeated school science. Students have been socialized into perceiving the world as a Newtonian world consisting of three-dimensional space, unidirectional and independent time, and interactions between independently existing objects. Science teaching has a major role in molding students' world views by providing concepts that impose some meaning on the world--'reality' is given sense, order and coherence. It should do this in a way that not only allows students to make sense of reality but also in a way that reflects the best current understanding of reality that is available in science. It is therefore argued that the goal of science education should be to speed up the rate of diffusion of current scientific insights about the nature of reality so that these are incorporated into students' modes of talking and perceiving (i.e., a 21st century mode of thought). Contains 73 references. (Author/NB)

21st Century Thinking and Science Education

by
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Title: 21st century thinking and science education

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Abstract

> ...learning in formal settings is geared to the materialistic, deterministic, atomistic, reductionist and objective vision of the universe that has been rendered unsupportable by quantum mechanics.
>
> Gough (1989)

Western culture's sense of reality has been shaped to a large extent by a mechanistic science world view (Dijksterhuis, 1986). Such a viewpoint still dominates the thinking promoted by school science. Quantum theory is the most successful physical theory that has been conceptualised; yet Newtonian thought is still one of the main pillars on which the present-day curriculum is based (Doll, 1989).

At the same time, educational theories regarding science teaching have largely been based on out-moded eighteenth century conceptions of the physical universe. Since, a primary goal of science education is the development of a 'scientific world view', the challenge for 21st century science education lies in devising an education theory that incorporates understandings achieved in quantum physics. At the very least, this involves posing a scientific world view that has not yet permeated school science.

Students have been socialised into perceiving the world as a Newtonian world consisting of three-dimensional space, unidirectional and independent time, and interactions between independently existing objects.

Science teaching has a major role in moulding students' world views by providing concepts that impose some meaning on the world - 'reality' is given sense, order and coherence. It should do this in a way that not only allows students to make sense of reality, but also in a way that reflects the best current understanding of reality that is available in science.

It is therefore argued that the aim of science education should be to speed up the rate of diffusion of current scientific insights about the nature of reality so that these are incorporated into students' modes of talking and perceiving (i.e. a 21st century mode of thought).

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Bio-data

Azam MASHHADI's doctoral thesis, at the University of Oxford, addressed the question of *What is the nature of the understanding of the concept of 'wave-particle duality' among Advanced level Physics students?* Following degrees in Physics and Astrophysics (University of London) and Astronomy (University of Sussex) he taught for several years at a college in London (UK) before completing a MSc in Educational Research Methodology (Oxford). His research interests include student learning, teacher education, the use of IT in education, research methodology, and philosophy of science.

Christine HAN's doctoral thesis was on *Citizenship Education in A Plural Society* at the University of Oxford. Following a first degree in Philosophy *(National University of Singapore)* she was awarded the Nanyang Technological University Overseas Graduate Scholarship to pursue research in the philosophy of education. As part of the M Sc in Educational Research Methodology *(Oxford)* she wrote a dissertation on the education of the emotions. Her research interests include topics in the philosophy of education, moral education, citizenship education, and philosophy for children. She is currently a lecturer at the National Institute of Education (Nanyang Technological University, Singapore).

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> Man tries to make for himself in the fashion that suits him best a simplified and intelligible picture of the world; he then tries to some extent to substitute this cosmos of his for the world of experience, and thus to overcome it. This is what the painter, the poet, the speculative philosopher, and the natural scientist do, each in his own fashion. Each makes this cosmos and its construction the pivot of his emotional life, in order to find in this way the peace and security which he cannot find in the narrow whirlpool of personal experience.
> Albert Einstein (1954: 225)

1. Introduction

As a new century approaches it is perhaps time to re-assess the foundations on which school science currently rests and the 'mode of thinking' that it promotes. A general argument will be presented for replacing the present form of science education with one more in keeping with the 21st century. The detailed structure of such a science curriculum is beyond the scope of this paper, but a 'flavour' of how such a curriculum would differ from the one currently offered will be presented.

Examination of the history of science and the history of philosophy shows that the two are mutually interlinked, each 'feeds off' the other. For instance, quantum physics has raised a number of philosophical questions about the nature of 'reality' and the nature of knowledge. The development of quantum physics was itself influenced by philosophical considerations (e.g. Niels Bohr's principle of complementarity). In the same spirit science and philosophy should provide insights for science education as we enter unknown territory, the land of the future.

2. The challenge of modern physics for the science curriculum

The quantum theory is currently the most successful theory in science, yielding descriptions for all the fundamental forces of nature, except gravity, and accounts for phenomena ranging from starlight to the periodic table. It has also been responsible for technologies ranging from nuclear reactors to lasers.

Quantum physics is the best explanation for natural phenomena that has yet been developed. However the understanding of the nature of reality or the conceptual *world view* projected by the current school science curriculum is overwhelmingly Newtonian or 'mechanistic' in character. Ken Dobson (1985: 191), for instance, points out, the science curriculum has not truly come to terms with the conceptual developments of 20th century physics:

> It is almost exactly 80 years [now 90 years] since the special theory of relativity, the significance of chance in physics and the wave-particle duality saw the light of day. These theories represented a revolution in thinking about the very basis of the physical description of the world, and cannot be treated as just another few lessons to be tagged on to the fag-end of a GCSE (or A-level) course.

On his part, Dobson suggests - rightly - that it is not enough merely to include in the curriculum the 'facts' of the new physics; the *way of thinking* that arise from these theories must be brought into physics (and science) education as well.

Science education has traditionally been structured around what is perceived to be the scientist's conception of the natural world. Since the primary goal of science education is the development of a 'scientific world view', the challenge for science education today lies in it devising an education theory that incorporates the understandings achieved in modern 20th century physics. In particular insights obtained in quantum physics.

Newtonian thought, however, is still one of the main pillars on which the curriculum is based (Doll, 1989). In addition Gough (1989: 227) cautions against educational theories that are based on eighteenth century conceptions of the physical universe, and comments that:

> ... learning in formal settings is geared to (a) materialistic, deterministic, atomistic, reductionist and objective vision of the universe... Indeed, it would

> seem that formal education teaches us to distrust our own perceptual systems rather than to exercise the perceptual skills bequeathed to us by natural selection.
> Gough (1989: 227)

3. What is a 'world view'?

At issue is the question of which conceptual framework or 'world view' that science education shoud be promoting. The science educator William Cobern (1989: 12) refers to world view[2] as:

> the culturally-dependent, generally subconscious, fundamental organization of the mind. This organization manifests itself as a set of presuppositions or assumptions which predispose one to feel, think, and act in predictable patterns.

A world view, therefore, refers to a set of beliefs, concepts and assumptions which may largely be subconscious. These assumptions order and systematise sense perceptions, and help to maintain a degree of predictability in a world of change.

The concept of world view is central to education because it is closely related to the concept of knowledge (Proper, Wideen and Ivany, 1988). Pepper (1942/1970: 2) refers to such an ontological and epistemological orientation as a 'world hypothesis'. He contends that everyone has and uses world hypotheses: however, they may not realise this because these are so intimate and pervasive. Kilbourn (1984: 35) too argues that everyone possesses a world view which influences what they think and do. A particular world view is, therefore, intimately connected with a particular mode of thought or way of thinking.

4. The mechanistic world view

Apart from being the most pervasive world view, the mechanistic world view has come to be regarded as the viewpoint of 'common-sense'; in fact, it is usually presented as the only possible way of apprehending the world. The modern, mechanistic scientific world view is essentially a Western construct that developed in the 16th to 18th centuries. It grew out of the success of classical or Newtonian physics which overcame the Aristotelian view which saw the world as an organism, and the Neo-Platonic view which saw it as a mysterious universe (Kearney, 1971).

Another dominant influence on our modern-day culture has been the philosophical revolution of the seventeenth century, including the growth of Cartesian thought. Descartes argued that the mind, or the conscious self, is distinct from the material self. Mind and matter are separate entities, with the implication that consciousness is a 'ghost in the machine'. A consequence of Newtonian physics is that consciousness has no role to play in an individual's relationship with the world; neither does it provide any heuristic advantage in understanding or modelling human behaviour.

At the same time, as Bronowski (1973) points out, the 16th century fascination with machines and mechanisms emphasised the growing conviction that the 'chain' of cause and effect could explain natural phenomena. Osborne (1987: 360), quoting Koyré (1943), comments that the development of Galilean-Newtonian mechanics involved the construction of a particular world view:

> (The founders of modern science, like Galileo) had to destroy one world and to replace it by another. They had to reshape the framework of our intellect itself, to restate and reform its concepts, to evolve a new approach to being, a new concept of knowledge, a new concept of science - and to replace a pretty natural approach, that of common sense, by another which is not natural at all.

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[2] Synonyms for 'world view' that appear in the literature are'world hypothesis' and 'world picture'; others include 'root metaphor', 'view of nature', 'view of reality', and 'perceptual framework'.

Apart from being mechanistic, Renaissance science was materialistic in that only the world of the senses was investigated. In particular, Newton's material causalism, which emphasised material properties, resulted in the reality of subjective experience being doubted and downgraded. This ultimately meant a reductionism in which all natural phenomena is explained in terms of material causality, with the whole is being understood purely by the behaviour of its constituent parts. As the philosopher Alfred North Whitehead (1933: 158) has noted:

> Newtonian physics is based upon the independent individuality of each bit of matter. Each stone is conceived as fully describably apart from any reference to any other portion of matter. ...Also the stone could be adequately described without reference to the past or future. It is to be conceived fully and adequately as wholly constituted within the present moment.

Apart from the independent individuality of matter, there is also the element of determinism. Schommers (1989: 3) points out, for intance, that there are two essential features of Newtonian mechanics:

> 1) The elements of the world, which move in an absolute space and an absolute time, are small, solid, and indestructible objects, always remaining identical in mass and shape.
> 2) Newtonian mechanics is closely related to a rigorous determinism, i.e., the future path of a moving object (e.g., a planet) can be completely predicted and its past completely disclosed if its present state is known in all details.

Hence, the future state of mechanical systems in the Newtonian world can *completely* be predicted if the present state is known.

At the heart of the classical paradigm, therefore, is the assumption that matter has substance and form independently of whether or not it is observed. Newton conceived of an absolute space, without relation to anything external, always similar and immovable. Motion is regarded as the translation of a body in absolute space. At the same time, the flow of absolute time is not liable to any change. The causes that enable true and relative motions to be distinguished are the forces impressed upon bodies.

Referring to Pepper's world hypothesis of mechanism (Pepper, 1970), Proper, Wideen and Ivany (1988: 550) comment that:

> Mechanism takes machine as its root metaphor, either a mechanical device in discrete mechanism, or an electrical machine such as a dynamo in consolidated mechanism.

Mechanicism essentially perceives the whole as a simple sum of its parts, with causal relations being linearly conceived and independent of context. As has been noted, key elements of this world view are the regularity, permanence and predictability of the universe(see Kearney, 1971: 24). Mechanicism is still the 'orthodox' world view and remains a pervasive view in Western culture, including science education (Kilbourn, 1984; Proper, Wideen and Ivany, 1988; Smolicz and Nunan, 1975; Whatley, 1989; Wilson, 1981; Woolnough, 1989). The development of quantum theory, however, over the first thirty years of this century has resulted in a new scientific paradigm. What are the implications of quantum theory generally, and specifically what are the implications for science education?

5. The post-mechanistic or 'quantum' world view

Systems governed by the laws of quantum theory are not determinate. Individual events, such as the decay of a subatomic particle, can occur spontaneously without any single event causing it. As Rescher (1984) argues, quantum theory is genuinely revolutionary in that there is a fundamental change of mind as to how things happen in the world. This is not a matter of adding further facts, but of changing the conceptual framework or world view itself.

While the theory of relativity was in many ways a continuation of 'classical physics', quantum physics represents a new conceptual revolution (Selleri, 1990). In less than a century, physics abandoned a world view consisting of concepts that were mechanistic, deterministic and largely absolute, and espoused a world view comprising concepts that are relative, frequently non-deterministic and inherently probabilistic in nature (Lahti, 1990).

Two characteristics distinguish quantum theory from classical physics. First, there is the notion of quantisation; this is the idea that physical quantities are not allowed to take a continuous set of values. Second, it is not possible to predict the outcome of an individual measurement. In 1925-26 the complete mathematical formalism of (non-relativistic) quantum theory was constructed by Heisenberg and Schrödinger. Using this formalism an astonishing range of effects in atomic physics, chemistry, biology, solid-state physics, and many other areas could be explained and predicted. The philosopher of science Bernard d'Espagnant (1979), however, points out that, even if quantum mechanics is regarded as no more than a set of rules, it still conflicts with a commonsense world view or 'local realistic theories of nature'. This commonsense world view is based on assuming that regularities in observed phenomena are caused by a physical reality whose existence is independent of human observers (i.e. Realism), also that inductive inference is a valid mode of reasoning (i.e. legitimate conclusions can be drawn from consistent observations), and that no influence of any kind can propagate faster than the speed of light (Einstein separability or locality).

There are a number of important implications for science education that arise from considering the nature of what is the best physical theory that has ever been constructed (i.e. quantum mechanics).

Any physical theory consists of a mathematical formalism, and a series of interpretation or correspondence rules for connecting the elements of the formalism (i.e. mathematical symbols and the rules for their interconnections) with the elements of our sensory experience (Braithwaite, 1955). Among physicsts and philosophers of science, however, there is considerable disagreement over the interpretation of the mathematical formalism of quantum mechanics. Today, seventy years after the formulation of quantum mechanics the interpretation of this formalism is still by far the most controversial problem in current research in the foundations of physics because of their implications for determinism and realism (and arguably for logic as well) (Jammer, 1974)[3].

It is beyond the scope of this discussion to fully discuss the continuing controversy with regard to the 'meaning' of quantum theory, but useful (and readable) reviews can be found in Baggott (1992), Squires (1986), and Schommers (1989). The key point is not the 'physics' of quantum physics, but the profound questions that quantum theory raises:

> What are the limits of human knowledge? Is the physical world shaped in some sense by our perception of it? Is there an element of randomness in the universe, or are all events predetermined?
> Horgan (1992: 73)

These questions lie at the heart of a 'post-mechanistic' or 'quantum' science education. Such a conceptual world view does not assume the necessity of absolute certainty, questions do not necessarily have an answer - let alone a 'right' answer which can be found in a textbook. Science is, furthermore, a dynamic human activity which involves questioning taken-for-granted assumptions.

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[3] Nick Herbert (1985), for instance, illustrates this considerable disagreement by outlining eight major models of 'reality' based on differing interpretations of quantum mechanics:
1. The Copenhagen interpretation, version (a): There is no deep reality.
2. The Copenhagen interpretation, version (b): Reality is created by observation.
3. Reality is an undivided wholeness (Bohm).
4. The many-worlds interpretation (Everett).
5. Quantum logic.
6. Neorealism (the world is made up of ordinary objects).
7. Consciousness creates reality.
8. The duplex world of Heisenberg.

The question now arises as to whether or not it is (theoretically) possible to develop such a world view or is the mechanistic world view inevitable?

6. Is the mechanistic world view inevitable?
It has been argued that Newtonian physics forms the basis of the mechanistic world view. Such a view of the world is often regarded as being inevitable. Indeed, the philosopher Immanuel Kant argued that individuals perceive a Newtonian world because of innate organising principles that are Newtonian in kind.

According to Kant, cause and effect refer to the time order of spatially separated events. Kant also believed that the individual's concepts of space and time are Newtonian in kind. He therefore suggested that the Newtonian ideas of space and time be taken as principles organising the many perceptions that enter the mind. As the historian and philosopher of science Arthur Miller (1996: 190) points out:

> In Kant's system of philosophy, space and time are regarded as *synthetic a priori* intuitions. This means that instead of being born with a *tabula rasa* [clean slate], we are born with *synthetic a priori* intuitions of space and time. These intuitions are hard-wired into the mind in order for us to organize experiences. Kant reasoned as follows: Representations of space and time must be prior to our sensations because we can neither perceive anything nor give an order to our sensations if we remove space and time.

According to Kant's theory of the cognitive organisation of experience, objects in the real world ('things-in-themselves') are unstructured sensations when they come into the range of the individual's sense organs. The individual needs the 'forms of intuition' (viz. Euclidean space and time) in order to perceive these sensations.

The eighteenth-century philosopher George Berkeley argued against such a viewpoint and, in criticising the Newtonian assumptions of an absolute space and time, argued that the representation of objects is the result of our perceptual and cognitive organs (a point that will be considered in more detail later).

Kant also argued for the necessarily true (or apodictic certainty) of three-dimensional Euclidean geometry. The acceptance of Newtonian space also meant the 'common-sense' adoption of three-dimensional Euclidean geometry as the only possible geometry for investigating nature.

The assumption made in school science education that this necessarily involves promoting Euclidean geometry and the Cartesian co-ordinate system needs to be considered.

The assumption made by Kant that geometry must be Euclidean was undermined in the 1820s with the development of non-Euclidean geometries by Bolyai and Lobachevskii. They both pointed out that no logical contradiction follows from denying Euclid's axiom of parallel lines (i.e. meeting only at infinity). An infinite number of geometries are possible, all of them perfectly rational (Selleri, 1990).

There is an assumption that the results of large scale experience must be expressed using classical concepts, and that classical concepts are inherent in all logical thinking about any subject (Bohm, 1970: 207). The physicist Werner Heisenberg (1959: 55), for instance, argued that:

> The concepts of classical physics are just a refinement of the concepts of daily life and are an essential part of the language which forms the basis of *all natural science*. Our actual situation is that we *do* use the classical concepts for the description of experiments ... There is no use discussing what could be done if we were other beings than we are.

Underlying such a perspective is that the world is made up of component parts which have, at any moment, a definite position and a definite momentum. In classical physics an essential feature of the concepts of space and time is characterising the location of an object using continuous Cartesian co-ordinates. However, the physicist and philosopher David Bohm (1970: 208) points out that such a way of thinking is not unavoidable. For example, the location of a pencil in everyday experience is not specified by giving its (Cartesian) latitude and longitude. Instead, the pencil is described as being:

> ... on a certain desk, which is in a certain room, which is in a certain house, on a certain street, etc. In other words, we locate the pencil with the aid of a series of *topological relations*, in which one entity is *within* or *upon* another.

Bohm goes on to point out that:

> The same is true of all laboratory experience. For in no experiment does one ever give an exact co-ordinate of anything (i.e. to an infinite number of decimals). Rather, in a typical measurement, one places a point *between* certain marks on a scale, thus once again locating it by means of a topological relationship. Indeed, in every experiment that can possibly be done, the notion of a precisely defined co-ordinate is seen to be just an abstraction, which is carried out when a topologically described experimental result is translated into the language of continuous co-ordinates.

Behind the abstract classical Cartesian co-ordinate description of the concepts of space and time, there is a more fundamental topology, which is, arguably, closer to that used in common experience, and more accurately describes natural phenomena.

The assumptions that Euclidean geometry and the Cartesian co-ordinate system must be incorporated into school science education is, therefore, not inevitable. Another pillar of the mechanistic world view is the assumption of the uncontroversial nature of Aristotelian logic.

7. 'Problems' with Aristotelian logic

Greek logic - as formulated by Aristotle and which forms a basis of the Western intellectual tradition - has a number of so-called 'laws of thought'. Among other things, these include the Law of Non-Contradiction and the Law of Excluded Middle. According to the Law of Excluded Middle, a thing must be either A or not-A, there is no middle possibility. The Law of Non-Contradiction states that A cannot be not-A, when not-A represents a category that has been created precisely so that A may be excluded from it (Bowes, 1986: 64). In theory, this 'law' is an analytical procedure for creating mutually exclusive categories; opposites cannot belong together. This either/or logic is assumed unconsciously in the world of everyday or 'common-sense' experience. These logical principles are offered as laws of thought, not as laws of thought in the mechanistic world view but laws of thought, period.

These laws are normally taken for granted, and it is assumed that these axioms define the way people think. The question arises as to whether or not these laws are necessarily true in all situations. Doubts arise once the meanings of 'is' and 'not' in Aristotle's laws are considered further (Macrone, 1995). Such words can be used in a number of ways, giving rise to semantic muddles. For example, consider a statement such as 'a daffodil is either yellow or it is not'. The simplicity of the statement is undermined by disagreement between individuals on how yellow a daffodil has to be to be 'yellow', and even perhaps disagreement on what 'yellow' means. Qualities, or predicates, are often subjective. Hence, the application of Aristotelian logic may require consensus on the meaning of the quality or object to which it is applied. In mathematics, problems may arise such as the impossiblity of proving that an infinite number is either even or odd. In quantum physics, there are also problems with ontological claims; for instance, it cannot be stated that 'light is either a wave or not-a-wave'.

It should be pointed out that some authors have argued that Aristotelian logic is not universally applicable and even that it is culturally relativistic. For instance, Putnam (1969), and Finkelstein (1969) both consider the question of whether traditional two-valued (Aristotelian) logic is a result of environmental conditioning, and argue that it is applicable only to a very large, but still limited range of macroscopic experience. Reichenbach (1951: 189) points out the full significance of departing from the Newtonian-Euclidean corpuscular model of nature, and the abandonment of the idea of corporeal substance:

> With the corporeal substance goes the two-valued character of our language, and even the fundamentals of logic are shown to be the product of an adaptation to the simple environment into which human beings are born.

In addition Winch (1970) and Foucault (1970) both argue that rationality is situated in cultural practices and criticise the traditional assumption of an abstract and universal logic as a form of covert imperialism. Such viewpoints need to be discussed with great care since it might open up a Pandora's box of undermining rational grounds for choosing between alternatives.

The key point here is not that Aristotleian logic should be discarded. Even if it were possible to do so, it is too powerful a cognitive tool to be abandoned. It would not be possible to function in the everyday world that we inhabit without such a form of logic. A new form of science education should explicitly discuss the nature of Aristotelian logic, and its use in the construction of rational arguments.

The psychological origin of the individual's intuition about logic lies in the development of the concepts of object, space and number. In the field of educational psychology Piaget and Inhelder (1956) have observed that the pre-school child's concept of space is topological but that by the age of 12 it is Euclidean. In an article on *The Child and Modern Physics*, the Swiss psychologist Jean Piaget (1957: 46) makes the further observation that:

> Contemporary physicists have abandoned some old intuitions about the nature of the physical world. They have, for instance, renounced the concept of the permanence of objects in the sub-microscopic realm: a particle does not exist unless it can be localized; if it cannot be located at a particular position, it loses its title as an object and must be described in other terms. Now by an extremely curious coincidence it is found that a very young baby acts with regard to objects rather like a physicist. The baby believes in an object as long as he can localize it, and ceases to believe in it when he can no longer do so.

Jean Piaget's researches on the genesis of the concepts of object, space and number, and the psychogenesis of atomism and the conservation laws provide a perspective on why certain seemingly *a priori* categories of thought apply to the macroscopic level of experience (Capek, 1971). To begin with, the concept of the atom as an invisible permanent object can be apprehended only after the idea of a permanent object in general is formed. However, the features of the classical concept of particle have not survived the conceptual revolution brought about by quantum physics. Specifically, intuitive corpuscular models have been found to fail when used on the microscopic scale. In other words, as Capek (1971: 452) expresses it,

> The 'particles' of modern physics are neither immutable, nor permanent, that is, neither indestructible nor uncreatable; their 'motions' cannot be traced along continuous trajectories nor can be even localized precisely. In truth, the very usage of the term 'particle' or 'corpuscle' is nothing but a mere inertia of the traditional language.

In other words a term in science has a meaning associated with it within a particular conceptual schema or world view. The same word may continue to be used even though one conceptual schema has ostensibly replaced another (e.g. Newtonian physics replacing Aristotelian physics).

Reigel (1973) argues that Piagetian formal operational thought is linked to Aristotelian logic, whereas a post-formal operational thought would be linked to the pre-Socratic Greek philosophy and to the dialectical philosophies of Hegel and Marx. Campbell and Bickhard (1986: 109) present the argument that formal operational thinking (which is based on

Aristotelian logic) restricts the thinker to an inadequate world view that has to be replaced by a dialectical world view. To appreciate quantum theory fully there needs to be a post-formal world view or mode of thought.

It was earlier noted that underlying the wide-spread 'common-sense' acceptance of the mechanistic world view was the assumption of the direct apprehension of reality. However, a contrary position has been taken by many philosophers of science (e.g. Feyabend, Hanson, Kuhn, Popper). According to this position, data is 'theory laden'; in other words, there is no such thing as 'direct observation'.

8. The theory-ladenness of perception and another look at 'common- sense'
An inherent feature of common-sense thought is the assumption that its tenets arise directly from experience. However, an integral aspect of what 'common-sense' is comprises the conclusions arrived at by a mind that is filled with presuppositions. As the anthropologist Clifford Geertz expresses it:

> Religion rests its case on revelation, science on method, ideology on moral passion; but common sense rests its on the assertion that it is not a case at all, just life in a nutshell. The world is its authority.
> Geertz (1993: 75)

Underlying the wide-spread 'common-sense' acceptance of the mechanistic world view is the assumption of the direct apprehension of reality, i.e. observations are not theory laden. However, as will be seen, understanding even the a simple everyday occurrence involves a complex interaction between an individual's cognitive and perceptual apparatuses.

Data can be analysed only within a framework of knowledge or 'conceptual framework'. Miller (1996: 80) points out that there is no 'theory-neutral' languge with which to describe observtions:

> Even the data of vertical fall were interpreted by Aristotle within a conceptual framework comprised of such assumptions as that there is no vacuum and there are four elements, each seeking its natural place, and so on.

Michael Polanyi (1964) likewise suggests that this contextual situation is analogous to Godel's Incompleteness Theorem, which points out that axioms in mathematics are never self-demonstrable but always refer to some wider system that always remains richer and ultimately undemonstrable. Similarly, Kuhn (1977) points out that the relative importance of a 'fact', its relevance, and even whether it counts as a fact at all, depends on the view of the world and the standards contained in a disciplinary framework. In other words, all knowledge is embedded within a historical, cultural, and social framework.

In the context of teaching science, what the teacher effectively is doing is initiating students into 'seeing' phenomena and experimental situations in particular ways, i.e. to start to wear the scientist's 'conceptual spectacles'. This is because, as the philosopher Karl Popper puts it:

> observation statements and statements of experimental results are always *interpretations* of the facts observed . . . they are interpretations in the light of theories.
> Popper (1963 : 47)

Indeed, Hanson (1972) in *Patterns of Discovery* has described the perceptual changes that occur with changes in background theory. In *Perception and Discovery*, he (1969: 215) goes on to point out that:

> The raw visual datum of Compton's cloud-chamber experiment consisted only of two divergent fuzzy lines. Only a very great deal of training in the theory and practice of physics equipped him to see these as the ionization tracks of an elastic collision between a photon and an electron.

People use concepts to impose meaning on the world - 'reality' is given sense, order and coherence. Concepts are the means by which we come to terms with our experience. Hence, the perception of the world depends on the repertoire of concepts at one's command (as well as one's individual attached meanings). In his play*Jumper*, the playwright Tom Stoppard recounts an anecdote which illustrates this point well:

> Meeting a friend in a corridor, Wittgenstein said: 'Tell me, why do people always say it was natural for men to assume that the sun went round the earth rather than that the earth was rotating?' His friend said, 'Well, obviously, because it just *looks* as if the sun is going round the earth.' To which the philosopher replied, 'Well, what would it have looked like if it had looked as if the earth was rotating?'
> Tom Stoppard (1972: 75), *Jumpers*

In other words, one's perceptions depends on the concepts that one has at one's disposal.

Further, it is possible to impose different interpretations on the data received, even where the same concept is used. Hence, what the science teacher is doing is attempting to convince the student to adopt not just a concept, but also the teacher's interpretation of that concept. In science teaching, there is often the assumption that this interpretation would be the same as that of the majority of the scientific community. This assumption ignores the fact that scientific concepts are in fact human constructions. On his part, the historian and philosopher of science Thomas Kuhn would probably argue that the associated interpretation changes as the dominant paradigm changes ('to see is to see as') (Sutton, 1992).

The point could also be made that a fundamental aspect of thinking is thinking from a particular point of view. For instance, thinking mathematically involves having a mathematical 'point-of-view', of seeing the 'world view' in the way that mathematicians do (Schoenfeld, 1987). The philosopher Ludwig Wittgenstein (1953) provides an example of this interpretive 'point of view' with his conceptual analysis of two uses of the word 'see'. Suppose that a person is looking at a line drawing which he/she sometimes sees as a rabbit and sometimes as a duck's head (the long bill of a duck being where the rabbit's long ears are). In one use of the word 'see' then he/she is looking at exactly the same object; yet he/she *sees it as* as two different objects without being able to show that difference to someone else by drawing it. Wittgenstein, therefore, argued that 'seeing as' (the second use of the word 'see') is not part of perception. 'Seeing as' is the result of the *interpretation* of perception.

Perception it has been argued, consists of the conceptual exploitation or interpretation of the natural information contained in sensations or sensory states. The neurophilosopher Paul Churchland (1979: 7) points out that the current forms of conceptual exploitation or interpretation are largely based on:

> ...the structure and content of our common language, and in the process by which each child acquires the normal use of that language...In large measure we *learn*, from others, to perceive the world as everyone else perceives it.

Since networks of beliefs are the bearers or determinants of understanding it follows that:

> The conviction that the world instantiates our ordinary observation predicates cannot be defended by a simple appeal to the "manifest deliverance of sense".
> Churchland (1979: 24)

The common-sense conceptual spectacles through which sensations are conceptually interpreted may be resulting in the systematic misperception of reality. Developments in science have brought about transformations in the concept of intuition and what is meant by common-sense.

It has been argued that observation is 'theory laden', and student's observations are influenced by any prior theory developed on the basis of previous experience. A number of factors including prior theories and context as well as procedural and conceptual frameworks can affect observation (Claxton, 1991). The philosopher of science Paul Feyerabend (1975) has also argued that verbal responses to sensory stimulation would be meaningless except for the 'interpretation' they receive by being semantically embedded in a conceptual framework (see also Hesse, 1970).

Paul Churchland (1979) points out that common-sense, which is the way the world is usually thought about and perceived, is itself theory-laden. This theory is based not just on attempts to make sense of our physical dealings with the world, but also on the use of language. As Churchland (1979: 13) expresses it:

> Our current modes of conceptual exploitation are rooted, in substantial measure, not in the nature of our perceptual environment, nor in the innate features of our psychology, but rather in the structure and content of our common language, and in the process by which each child acquires the normal use of that language. By this process each of us grows into a conformity with the current conceptual template. In large measure we learn, from others, to perceive the world as everyone else perceives it. But if this is so, then we might have learnt, and may yet learn, to conceive/perceive the world in ways other than those supplied by our present culture. After all, our current conceptual framework is just the latest stage in the long evolutionary process that produced it, and we may examine with profit the possibility that perception might take place within the matrix of a different and more powerful conceptual framework.

The meanings that words have are partly derived from a slow diffusion into the common culture of the work of research scientists. However, because this diffusion is relatively slow common-sense is built on an out-of-date science. As Lucas (1985: 165) expresses it:

> The abandonment of Newtonian mechanics as a paradigm for understanding reality is relatively well advanced. Yet, the metaphysical view of the world it once inspired has proved rather more durable. Perhaps because of cultural lag, only in recent decades have the philosophical implications of quantum physics begun to reverberate through other knowledge domains. Overall, the new image of reality unfolded by modern science portends a radical revision of how the world and human consciousness itself is to be comprehended.

The aim of science education should, according to Churchland, be to speed up the rate of diffusion so that the modes of talking and perceiving incorporate the current scientific insights about the nature of reality. Guy Claxton (1993: 197-8) points out that Churchland's assumption is that we have been socialised into perceiving the world as a Newtonian world consisting of three-dimensional space, unidirectional and independent time, and interactions between independently existing objects. Churchland's agenda for science education therefore raises an interesting challenge:

> ...if relativity and quantum theory are more accurate descriptions of reality, could we not learn to see it in those ways - and how would it look if we did?
> Claxton (1993: 198)

Chapman (1993: 115) similarly points out that:

> ...there was a time when it was the Aristotelian, rather than the Newtonian, world-view that held sway. In its time, wasn't that view also thought to be rooted in common sense? Is common sense anything other than that which we have been enculturized - indoctrinated - into accepting? Perhaps it is time we took seriously the need to enculturize our young people into what might be termed a Heisenbergian world view?

The driving mechanism behind the development of a world view is the individual's need to relate to the external world. The child interacts with the physical and social environment and through this interaction the presuppositions underlying a common-sense world view, say, are unconsciously constructed. Following on from the early formative years of childhood comes the formal education of schooling, as well as family and society. A world view provides a foundation upon which cognitive framework (for interpreting the world) are built during the learning process. Kearney (1984: 3) refers to this whole process of world view development and change as 'dialectical constructionism'. It has common features with Piaget's genetic epistemology and Ausubel's constructonist theory of learning (Ausubel, Novak and Hanesian, 1978).

The question now arises - how could one move from a mechanistic interpretation of perception to a post-mechanistic interpretation of perception?

9. The role of language

Physicists have *created* a language describing fundamental components and symmetries of 'the world' which are not observable. For instance, quarks are said to come in three colours. The word 'inertia' does not refer to an object or entity, but to a concept somehow acquired from the experience of trying to move heavy things (Wellington, 1983). Words for unobservable entities such as 'electron' cannot be derived from direct experience and can only have 'meaning' in a theoretical context (Herrmann, 1994). Hence, science has constructed 'models of reality', which attempt to provide an unified systematic 'picture' that not only describes unobservables; it may also describe a range of seemingly unrelated phenomena, and predict unknown phenomena and direct further inquiries about the world.

Holland (1993: 8) points out that even one of the founders of quantum theory, Niels Bohr, assumed that everyday language, and its formulation in classical physics (particles, fields, position, momentum, energy) is a natural and necessary mode of discourse for people to communicate their experiences. Classical physics, however, developed over millennia, and requires many years of schooling to learn. Language is not static, and depends upon and contributes to a changing social context. 'Everyday language or experience' is in a state of flux. For instance, the idea that a body continues in a state of uniform motion unless acted upon by a resultant force would run counter to common-sense for Aristotle, but would be natural for Galileo. The role of language in constructing meaning or mental models of phenomena would need to be explicated by a new form of science education.

The question does arise as to why should everyday language not eventually come to include concepts that enable quantum phenomena to be conceptually accepted? The linguist Benjamin Lee Whorf suggests that through the linguistic systems in our minds we project our grammar onto the world:

> Every language binds the thoughts of its speakers by the involuntary patterns of its grammar...Languages differ not only in how they build their sentences but in how they break down nature into the elements to put into those statements... For example, English terms, like "sky". "hill", "swamp", persuade us to regard some elusive aspects of nature's endless variety as a distinct *thing*, almost like a table or chair. Thus English and similar tongues lead us to think of the universe as a collection of detached objects of different sizes...Thus as goes our segmentation of the face of nature, so goes our physics of the cosmos....
> Benjamin Lee Whorf (1950: 153)

At the same time, any language has to have some kind of grammatical structure. This structure incorporates tacit assumptions that direct individuals to direct attention to attend to particular aspects of what goes on in and around us and to ignore others. Hilgartner and diRienzi (1995: 475) argue that this, for instance, results in a presupposition of a fundamental dualism:

> ...we project the structure of our grammar onto the cosmos. And in so doing, we presuppose a fundamental dualism, with the cosmos divided into two parts: an immaterial or mystical side (verb-like, and suggested by terms such as "soul" or "spirit" or "mind"), contrasted against a material or physical or "real"

side (noun-like, and suggested by terms such as "body" or "the physical" or "matter").

With regard to science education, a science curriculum which incorporated modes of discourse or thinking which reflected the 'best' understanding of reality that we have at present would lead to the gradual realisation that the mechanistic conceptual framework is not the only possible world view.

10. General characteristics of a post-mechanistic science education

To summarise the argument so far, it was earlier noted that school science education promulgates a materialistic, deterministic, atomistic, reductionist and objective perception of the world that has been undermined by the interpretation(s) of the formalism of quantum mechanics. In addition underlying the wide-spread 'common-sense' acceptance of the mechanistic world view was the assumption of the direct apprehension of reality. However, data is 'theory laden'; in other words, there is no such thing as 'direct observation'.

Given the above the best conceptual and perceptual theory of 'reality' produced by modern day science should form the basis of school science education. Such a post-mechanistic or quantum world view would involve, among other things, exploring the construction of human knowledge, explicating the use (and limitations) of Aristotelian logic, understanding the 'theory-ladenness' of observation, realising the role of language in constructing meaning, accepting the role and impact of the observer on what is observed (i.e. non-separability of subject-object), and appreciating the usefulness of both the reductionist and holistic approaches. These characteristics of a new form of science education would now need to be turned into a science curriculum.

11. Conclusion

Science is valued for its practical achievements, but according to the philosopher Karl Popper (1963: 102) it should be valued even more for its ability:

> ...to free our minds from old beliefs, old prejudices, and old certainties, and to offer us in their stead new conjectures and daring hypotheses. Science is valued for its liberating influence - as one of the greatest forces that make for human freedom.

The development of a post-mechanistic or 21st century science curriculum, therefore, involves the development of a liberating mode of thinking or new conceptual world view - a true 21st century mode of thought.

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