SOME METHODOLOGICAL/PHILOSOPHICAL PROBLEMS IN SECONDARY SCHOOL SCIENCE EDUCATION

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ABSTRACT

An examination of common images of science and the scientist, and of some conceptions of 'science processes' in secondary school science, as depicted in texts, curricula and other public utterances, reveals the influence of certain traditions of philosophy/methodology. The methodological/philosophical positions associated severally with Bacon, Locke and Hume, and the Logical Positivists, are collectively designated as 'Methodological Reductionism' in this study, and are explored and found to be inadequate and/or misleading in the light of recent developments in the philosophy of science. Dissatisfaction with current school science is also found to be a consequence of adoption of narrow, 'functional' goals of science education. Difficulties also arise from: confusion of meanings of scientific terms in relation to their 'ordinary language' usage as contrasted with their specialised scientific usage; teachers' attitudes towards, and understanding of, the nature of science; and teaching methods which despite innovations, have remained essentially content-oriented, fact-laden, formal and didactic. It is argued that if science education is to regain its interest and become educationally more meaningful for students, then an alternative methodological/philosophical rationale for science and 'science processes' is desirable. It is suggested that the adoption of what is basically a Kuhnian epistemology may help to remove misconceptions about science and the scientist, and also help to surmount some of the current difficulties in the teaching of science. To facilitate and accommodate conceptual changes in science education, a teaching and learning strategy based upon Kuhn's notions of 'paradigm' and 'paradigm change' can be utilised. Because current science education is said to be overly formalistic and socially isolated, it is recommended that a multi-disciplinary approach may not only regain for science

its declining interest, but also produce future citizens who are better equipped to deal with science/technology/ society problems and issues, and who will possess the cognitive and affective attributes needed for making a positive contribution within a science- and technology-based society.

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On my return to Massey University in February 1983, on the suggestion of Mr E.L. Archer, I approached Dr David Stenhouse with a view to his taking over supervision of the thesis. In the course of the research it has become apparent that, working independently from our different starting-points, we had already converged on substantially similar diagnoses of the perceived problems and possible remedy. Dr Stenhouse has kindly made available various items of his own theoretical research both published and in press, and where relevant, I have cited these works by explicit references in this thesis. Beyond this, many general methodological issues have been greatly clarified in the course of discussions, and I wish to place on record my grateful appreciation to Dr Stenhouse for his very substantial contribution as Supervisor of this work.

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CONTENTS

INTRODUCTION

In recent times there has been a growing concern amongst scientists, science critics, environmentalists, educationalists, 'sociologists of knowledge', and some of the general public about the consequences of certain scientific and technological developments. This concern arises out of a state of affairs in which people everywhere fear the dangers, only recently apparent, of the uncontrolled advances in science and technology especially as they affect the society. While, on one hand, people are readily accepting the benefits and commodities resulting from the continuing scientific and technological developments, on the other, they are showing an increasing uneasiness brought about by the threat of overpopulation and resulting environmental pollution, depletion of non-renewable resources, inequitable distribution of wealth, and especially the many dangers of nuclear catastrophe. There are moral issues raised by certain lines of research, and questions about the relative economic value of some areas of scientific research, in relation to massive and urgent world and/or national problems. Furthermore, there is the mounting criticism of the wholesale adoption and application of 'scientific norms' in our thought and behaviour; and to some extent we are now witnessing a rejection of the 'scientific mode of analysis' by those who are concerned about the dehumanising effect of modern science and technology.

The problems associated with the impact of science and technology on society suggest that there is a need for the democratization of technological decision-making. One possible way to achieve this goal is through science education whereby an awareness can be developed that citizen participation in science-related policies is desirable. Science education can also, in turn, develop in future scientists an awareness of their social responsibility as part of their scientific activity. But science education is currently available to a large percentage of the people and we could therefore expect it to be adequate and to be capable of meeting the needs as new problems arise. However, there are specific problems confronting not only scientists but also science educators.

The effects of the threat associated with scientific and technological developments are

(i) a loss of confidence in science and scientists and

(ii) a rise in suspicion and hostility towards science and technology.

Symptomatic of these are the 'drift' of students away from the sciences, and the emergence of various groups protesting against different activities and developments that are linked to science and technology. Such symptons imply

(i) that there is something wrong with/about modern science itself, and/or

(ii) that science education is presenting an inadequate view of the nature of science.

Present indications are that science is under external pressure to put its house in order and to adapt itself so as to meet the needs of the future. In response to potentially dangerous changes in the biosphere, a world-wide environmental protection movement has sprung up. And this movement has done more than criticize activities and developments responsible for different types of pollution, health hazards associated with food additives, possible radioactive leakage from nuclear reactors, the nuclear arms race, physical destruction of the environment, etc., etc.. It has also forced people to rethink their dependency on nature. As a consequence, instead of the view that humanity should be engaged in a war against nature, such movements are providing a fresh view that emphasises harmony with nature. At the scientific level, this has led to studies aimed at understanding ecological relationships. There is now an emerging appreciation of the complexity of these relationships. This means that not only the scientific community but society itself needs to reconceptualize science and technology in terms of recycling, renewability, the carrying capacity of natural systems, and so on.

While it may be, that the problems associated with science and technology are a result of a misdirected view of the relationship between nature and science, this thesis will attempt to show that science education is itself contributing to the problems. It will be argued that school science along with its translation into practice embody images of the nature of man as scientist, of scientific knowledge, and of the relationships between the two, which contribute to the problems. It will be shown that the philosophical/methodological foundations of science subjects as these are presented in schools, give rise to conceptions of science, science 'processes', and the scientist that are inadequate and misleading. Such an exercise as examining the philosophical/methodological foundations of school science will be largely inferential since textbooks contain few explicit statements of position on philosophical matters. Science textbooks may reflect the views of the authors but the authors themselves may not be entirely conscious of any particular philosophical position. It may be more reasonable to suggest that the current textbooks and science programmes are more likely to reflect generally accepted views and these views are collectively held by the practising school science community.

The overall situation can be separated into two groups of considerations: effects and possible causes. The effects of science and science education to be studied are:

(i) decline in confidence in (and even some symptoms of hostility towards) science and technology;

(ii) students' misunderstanding of science and dissatisfaction with school science;

(iii) gap between understanding of science and the social and personal needs for such an understanding; and

(iv) the drift from science subjects.

All these effects are interrelated in mutually causal ways. It will be shown that there is no one single, independent variable. There are several sources of the current problems associated with school science. These are

(a) images of science and the scientist as held by students and teachers;

(b) conceptions of 'science processes';

(c) teachers' and students' understanding of the nature of science;

(d) the influence of certain scientific doctrines such as scientism, reductionism, etc. on society in general;

(e) schools' perception of the purpose of science education;

(f) specialisation and fragmentation of school science;

(g) teaching that appears to be formal, rigid and paradigm-bound; and

(h) certain other closely related features of school science.

This thesis will attempt to show that the above mentioned characteristics of secondary school science reflect certain influences, in particular the influence of some of the tenets of science posited by traditional philosophers of science, especially Bacon, Locke, Hume and the Logical Positivists. For the purpose of this thesis certain traditions of science attributed to Bacon, Locke, Hume and the Logical Positivists will be collectively identified as the tenets of the "Methodological Reductionists'. The term 'Methodological Reductionism' is to be used merely as a designation for some features and not all the features and is not intended to be definitive of everything said by Bacon, Locke, Hume and the Logical Positivists. It is being used in a limited way in this study. By highlighting the weaknesses inherent in some of the traditions of science attributed to the 'Methodological Reductionists' it will be possible to expose the corresponding weaknesses in secondary school science. If it is to be assumed that aspects of the philosophies of the 'Methodological Reductionists' have influenced science educators' conceptions of science, 'science processes' and scientists, then to point out the fallacies/anomalies in the traditional interpretations of science should provide a basis for rejecting images and myths fostered within school science.

The problems associated with science and technology and the inability of science education to offer ways and means of not only understanding why the problems exist but how to alleviate them, are all matters requiring solutions for several reasons. Science and technology are of fundamental importance to society. Any drift from the sciences could well mean a decline, qualitatively and quantitatively, in the number of students selecting careers related directly to science and technology. A regular supply of scientifically and technologically skilled manpower is necessary for the existence and maintenance of most modern societies. The supply of manpower is not the only reason. The increasing interaction of the individual with science and technology and the nature of modern day scientific research especially in the field of molecular biology suggest that a population that is more scientifically literate is desirable. This does not mean that the citizen need to know about the molecular structure of dioxin, heat and pressure cycles of motor car engines, or the recombinant DNA process. The citizen should have sufficient knowledge to evaluate scientific and technological practices so as to counteract possible abuse of decision-making power vested in a few.

The purpose of this thesis is, therefore, to identify some of the weaknesses in science education and to suggest strategies of change. In Chapter one, I shall provide a brief outline of some of the reasons for the increasing concern about the implications and consequences of scientific and technological activities. The decline in confidence in science and the emergence of public suspicion of 'experts' would naturally affect people's image of scientists. This will be considered in the next Chapter and it will be shown that the image of the scientist fostered by school science lends support to the view that the purpose of science is to subjugate nature, that science is neutral and that students of science must strive to imitate the scientists by being 'objective', 'rational', 'emotionally neutral', etc.. The cold, impersonal image of the scientist will be shown to contribute to the drift away from the sciences; it will be also shown that such an image of the scientist has a strong appeal to certain types of science aspirants - aspirants who admire characteristics or behaviours that are devoid of emotions and feelings. It is claimed that Gagne's conception of 'science processes', upon which much of the curriculum development and instructions in science are based, have been influenced by the epistemologies of the 'Methodological Reductionists'. In Chapter three, I shall investigate the epistemological bases of Gagne's theory of the learning hierarchy, and attempt to show the extent of the influence of the tenets of the 'Methodological Reductionists'. In light of recent developments in the philosophy of science it will be possible to argue that a commitment to inductive empiricism, a tradition closely associated with the Methodological Reductionists, leads to a presentation of a misleading and inadequate view of 'science processes'. In Chapter four, I shall show that the legacy of certain aspects of the philosophies of Bacon, Locke, Hume and the Logical Positivists is inherent in school science as evidenced by the projection of such images as: science is neutral, infallible, and true; the central role of science is to facilitate man's domination over nature, science will provide answers to all social and environmental problems; all scientific phenomena can be explained if they are reduced to physics and chemistry. The limitations resulting from a commitment to such views will be considered. In Chapter five I shall (a) examine the major goals of science education and then show the kinds of problems arising from these goals, (b) argue that the current practice of formal initiation into the dominant paradigm of science fails to make science education as educationally worthwhile as it ought to be, and (c) examine teacher attitude, training, and understanding of the nature of science in order to point out the need for improvement in these areas. In the final Chapter, I shall outline a possible strategy for change in the hope that this strategy may help to remedy or at least alleviate some of the problems now confronting secondary school science.

CHAPTER ONE

CURRENT CRISES IN SCIENCE AND SCIENCE EDUCATION

The purpose of this chapter is to provide an outline of some of the major problems of humanity brought about or aggravated by scientific and technological developments, and to show that in some ways, current approaches in science and technology, as perceived through formal education, the communications' media, etc., have contributed to continuing dissatisfaction with school science. In later chapters I shall consider assumptions as to the nature of science which are inherent and/or explicitly stated in science education, in order to argue that some of these assumptions not only lend support to inadequate and/or erroneous public views of science and technology, but also contribute to systematic misorientations within school science.

Initially, I shall examine some of the reasons for the growing public concern about scientific and technological activities, and then point out the effects arising from this concern in terms of the public attitude towards science. I shall also consider the repercussions that an adverse attitude towards science and technology has upon science education. I maintain that outlining the problems associated with the impact of science and technology on society provides a basis for raising the question: Whether current school science is adequate and if not, why not?

Some of the pressing global problems

It is acknowledged that dedication to the furtherance of industrial and technological achievements has helped to produce remarkable accomplishments, but the failure or inability to foresee the adverse consequences of some of these advances cannot be overlooked despite the material gains.

The threat of overpopulation (Ehrlich & Ehrlich, 1970; Metcalf, 1977) is perceived as one of the problems that the human society faces today. The global population in the mid-1950s stood at 2.75 billion (2.75×10^9). Today it is over 4.0 billion and by the year 2006, it is expected to be about 6.8 billion (Baez, 1976; Toffler, 1980). The greatest immediate increment is projected to take place in the developing countries where 75 per cent of the world's inhabitants live. These spectacular increases have been made possible by developments in health and in agricultural technologies. Advances in medicine have produced dramatic results in the conquest of disease. Infant mortality rates have been greatly reduced, while life expectancy has risen steadily in most countries.

In conjunction with the threat of overpopulation there is the problem of increasing poverty (Penchef, 1971). In the world today, one quarter of the population live in relative affluence and three quarters in relative poverty; 800,000,000 people live in what the World Bank terms 'absolute poverty', and fully 700,000,000 people are underfed[1]. In human terms, poverty means malnutrition, protein deficiency with possible brain damage especially to children. Poverty is widespread but more so in the poorer countries of Asia, Africa, and Latin America. Today, a widening chasm separates rich and poor nations. The rich appear to have benefited from the technological revolution by continuously improved standards of living. But a similar technological revolution has not occurred to the same extent in the 'poor' countries. The technological advances which have brought a lower death rate have not been successful in reducing the birth rates, consequently there has been a greater demand for

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1. Figures on poverty, health, and nutrition are from Robert S. McNamara, addresses to the Board of Governors of the World Bank, 24 September 1973, and 26 September 1977 as cited by Toffler, 1980.

increased food production. Unfortunately, food production in the poorer nations has not been able to keep pace with the rapid growth in population (Kaiser, 1969). The Green Revolution does not look so green when we consider its increasing dependence on the application of expensive petroleum-based fertilisers that have to be purchased abroad. Instead, the Green Revolution has made the poor more, not less, dependent on the rich.

In view of the plight of the poorer nations, enormous investment in space technology and nuclear weapons has raised questions about the relative benefits of such an outlay. India's recent launching of a spacecraft and plans to spend more than N.Z.$1.5 billion on its space projects in the next seven years have led to doubts as to the necessity for such an investment. These doubts arise from the observation that investments by advanced countries in space technology have not firmly established that researches of the present nature can provide answers to the pressing problems of a developing economy.

Industrial growth, increases in population, and, to some extent, improvements in standards of living have resulted in a greater demand for material goods. These phenomena are leading to a rapid depletion of non-renewable resources and to ecological pollution (Harvey & Hallett, 1977; Metcalf, 1977). The problem of pollution is not confined to specific geographical areas but is global in extent (Eckholm, 1976; Norman, 1982). Scientific and technological advances have contributed to increased industrialisation with the unfortunate consequence of the deterioration of the human environment. One of the elements of the biosphere that is affected most by ongoing destructive processes is the air. Air over high density industrial areas contains an assorted mixture of metallic oxides, tar, dust, carbon, aerosols, mists of oil, sulphur dioxide, oxides of nitrogen, photochemical smog (produced by the action of sunlight on the gases from automobile exhausts) as well as other chemical fumes, crop sprays and radio-active particles (Bennett, 1975; Porteous, Attenborough & Pollitt, 1977; Horne, 1978; Bolin, et al. 1979). This conglomeration of gases and particles has been found to be not only detrimental to the health of the human society but is said to be destroying the delicate ecological balance of the entire planet. Aerosol propellents e.g. chlorofluorocarbons are claimed (Ehrlich, Ehrlich & Holdern, 1977) to deplete the ozone layers while jet propelled planes are said to use up large amounts of oxygen in the air. A single jet plane, for example, burns 35 tons of oxygen in one trip across the Atlantic (Penchef, 1971). Deforestation of whole regions and expanding cities have resulted in the increase of carbon dioxide content of the air. Disposal of industrial wastes and discharge of sewage are polluting streams, rivers and even oceans. A fairly significant number of lakes and rivers in several parts of the world, including the third world countries (Norman, 1982), can no longer sustain marine life because of the increased toxification and depletion of the oxygen content of the water. Both food production and economic development prospects in Africa, Asia and Latin America are now dimmed by accelerating destruction of the land's productivity through rampant deforestation resulting in the erosion of precious topsoil and an increase in flooding due to siltation (Eckholm 1976; Norman, 1982).

Suspected changes in climatic conditions (Bennett, 1975) have also been attributed to atmospheric and themopollution. Scientists tell us that urban development, industrialisation and energy transfer now have a significant effect upon global weather patterns. We hear on the one hand of the 'greenhouse effect' which tends to raise atmospheric temperature as a function of increased carbon dioxide production (Hutzinger, 1980); but on the other hand some argue that increased amounts of pollution in the air will tend to lower atmospheric temperature by decreasing the amount of solar radiation reaching the earth's surface (see Commoner, 1974; Metcalf, 1977). Some scientists, extrapolating from present observations, speculate that it would take about ten years to decide which is the more powerful effect[2] - and that by then, large-scale climatic changes may be irreversible (for detailed discussion on environmental pollution and degradation of the environment see Love & Love, 1970; Commoner, 1974; Eckholm, 1976; Ehrlich, Ehrlich & Holdern, 1977; Harvey & Hallett, 1977; Metcalf, 1977; Higgins & Burns, 1978; Horne, 1978; Norman, 1982).

There are controversial issues associated with certain lines of research. Advances in the field of molecular biology have raised questions about whether certain developments taking place are morally justified (Davis, 1983). The biological revolution in genetic engineering has made possible the manipulation of living materials through cloning and recombinant DNA technology. Some of the goals are admirable for example, the production of insulin through DNA technology (while human growth hormone and interferon are under production). There are plans to use the DNA technology to produce vaccine and many other therapeutic and diagnostic agents. However, predictive medicine in which genetic markers (including DNA variants) are used for antenatal and prenatal diagnosis of genetic diseases and the manipulation of DNA in human fertilized eggs are areas of genetic engineering that pose new questions of confidentiality, private versus societal goals, and self-determination (Motulsky, 1983). There are researches being undertaken involving the insertion of human genes

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2. New Studies from the Environmental Protection Agency and the National Academy of Sciences (Time, 31 October, 1983, p.50) reveal that "the earth is warming up from all the carbon dioxide being spilled into the atmosphere ... and worse, the first effects of the climatic changes could be felt as early as the 1990s." Some of the effects predicted are: flooding in some low-lying areas and drastically changing rainfall patterns.

into the DNA of microbiologic vectors, such as the intestinal bacterium Escherichia coli, where the human DNA becomes integrated. There could be hidden dangers in such a genetic manipulation. Scientists are now considering the possibility of producing oil-digesting bacteria. There are speculations about the possiblity of making metal-hungry micro-organisms capable of 'mining' valuable trace metals from ocean water. There is anxiety that genetic manipulation of bacteria could result in the creation of pathogenic bacterial strains that might cause mass epidemics (Watson & Tooz, 1981). According to Toffler (1980), there are dangers of deliberate spread of diseases through the release of pathogens. Questions already arise, such as: Should we clone individuals with particular traits and capabilities? Should we use genetic forecasting to pre-eliminate 'unfit' babies? Certainly, such questions and even their answers need to be considered in the future. Wild as these notions may sound at present, these *are* issues that may and will have to be faced by future generations. Each of these possibilities has its own advocates and adversaries in the scientific as well as in the commercial communities. There are also science-related practices of concern to the consumer, for example, the pumping of growth hormones and antibiotics into domestic animals destined for dinner tables, and the addition of food additives and preservatives to packaged and canned goods, etc. Do the criteria of costs and short-term benefits acquired override the possible long-term effects on humanity?

At the conscious level, it is said that the all-pervasive influence of science has led to a ready acceptance of scientific 'objectivity' and 'rationality' (the meanings are to be explained and discussed in Chapters 2 and 3) in analysing human thought and behaviour. Humans are being treated, often, as purely mechanical objects. In the social sciences we discern a trend towards trying to understand social issues through dispassionate analysis i.e. towards objectivity. While objectivity is worth pursuing, Andreski (1972: 98-9) maintains that when discussing human affairs it is not possible completely to suppress one's own feelings. To assume that objectivity provides the best basis for studying human affairs is not entirely feasible because, according to Andreski, an emotional involvement may well prompt untiring curiosity which is one form of all scientific activity.

The world now appears to have become more and more sceptical of the claims and pretensions of science and technology. The increasing criticism, as Bloch (1972) suggests, is a consequence of the people's perception of how science and technology have contributed

> to the deterioration of our world - or rather in the uncontrolled application of scientific technology that leads to the now well-known problems of environmental pollution, the use of science for war and destruction and the social implications of the by-products and side effects of medical progress - and in fact that science and technology have failed in many people's view to make our lives happier and more meaningful (p.3).

Besides merely uttering criticisms, we now witness the emergence of various environmentalist, 'consumer' and other politically active groups that are increasingly demonstrating their concern about the ecological, health and other implications of certain technological and industrial developments. There is a growing awareness of the fragility of the earth's biosphere, and growing realisation that this planet will simply no longer be able to withstand even the present level of industrial onslaught. It is also becoming apparent that society can no longer rely indefinitely on non-renewable sources of energy, which until now have been the main backbone of industrial development.

Over the last two decades, an increase in anti-scientific mood has been noticed. This mood finds expression in the writings of the counter-culture movement

(Roszak, 1969 & 1972) and in the left-wing intellectual revolt against a system which it is believed by some, is legitimated and supported by science and technology (Marcuse, 1968; Habermas, 1971; Rose & Rose, 1969 & 1976; Albury and Schwartz, 1982). There are also repeated warnings by certain scientists about the continuance of inadequately controlled growth of science and technology (for example, Commoner, 1972).

Toulmin (1972) sees these anti-scientific rhetorics as genuine indicators of the failure of science and technology in certain respects. Scheffler (1967) considers the present attack on science as not just disenchantment with science but a revulsion against all rationality and objectivity. Whether such an extreme view can be sustained will be investigated as we proceed.

Decline of confidence in science

While there is continuing criticism of many consequences of science and technology, a decline in confidence in the very nature of modern science has also been recorded. National data on public attitude towards science, collected by Withey and Davis (1968), indicate that most Americans during the fifties valued science highly because they regarded progress in science and technology as the basis for greater material benefits. Very few questioned the nature and direction of scientific research. The status of science was high and people felt the world to be 'better off' because of science. The public often tended to cite improved health, a higher standard of living, and other material gains to justify their support for science and technology. During the sixties, a shift in the public's attitude towards science and technology was noted by Oppenheim (1966). He found that the public's sense of threat from science increased from 43 percent of the sample interviewed in 1957, to 57 percent in 1964. His study also indicated that the proportion of the people who viewed science as breaking down people's ideas of right and wrong rose from 28 percent of the population in 1957 to almost 42 percent in 1964. While the majority of the people viewed science favourably in the fifties, in a somewhat materialistic sense, this appreciation did not remain stable or improve in the sixties. The Louis Harris poll and the American National Research Centre data (cited by Etzioni and Nunn, 1974) revealed that the public's confidence in the sciences and the scientific community dropped 19 percentage points from a high of 56 percent in 1966 to 37 percent in 1973. Latest NSF-sponsored survey (Walsh, 1982) shows that the American public's general attitude towards science and technology continue to fluctuate. There is now a widely held belief among scientists and non-scientists that appreciation of science in the United States and England is still on the downturn, or at least not as favourable as in the era of relatively uncritical approval in the late 1950's. One opinion is that "science and technology have taken a severe pounding from which they will not recover" (Clarke,1973: 66). That there is a deep mistrust of science and technology seems fairly evident (Schmandt, 1971; Pitzer, 1971; Bloch, 1972; Weisner, 1973; Walsh, 1982). Time magazine (23 April, 1973) described the public's reaction to science as "one of deepening disillusionment" (p.83) and a later issue (14 May, 1979:58) has commented that the public has a distrust of experts - the scientist, the technician, the engineer, and the specialist - and this feeling of distrust has been further aggravated by the nuclear reactor accident on Three Mile Island in Pennsylvania.

The above reviews, encompassing almost three decades, provide evidence that there is a gradual decline of confidence in science and technology in the 'scientifically-informed' circles as well as among the general public (Walsh, 1982). Since progress in science and technology (and therefore in the various aspects of society) is dependent upon public support, increasing distrust of science and technology can only hinder progress.

'Progress' is not, of course, limited to materialistic benefits of science and technology - but without these, various other dimensions of progress seem likely to be limited. The problem of a decline in confidence is further compounded by evidence of the drift from science.

The drift from school science

In the United States, a steady decline in enrolment for physical science courses since the late sixties has been noted by Ronnenberg (1970), Lerner (1971), and Uzelac (1973). During the "Snowmass" Conference - an international conference on education in chemistry - held in Colorado in 1970 (as reported in the Journal of Chemical Education, 1971), members noted their concern for the decline in the number of students in physical sciences. Their concern was even greater when they found that "anti-science is growing in one critical group where we had expected to see it least - among the bright young people" (p.22). This decline has been found to have spread to the number of science and mathematics graduates enrolling for teachers' courses in both teachers' colleges and university departments of education. Demographic information obtained from thirty five of the largest graduate centres for science education in the United States (Yager et al., 1982) show a decrease in the average number of graduates (bachelor's degree) in such centres. Other findings also support this trend. An annual survey of entering college freshman, conducted by UCLA and the American Council on Education (Science, 18 February 1983), shows that this year's (1983) freshman are distinctly cool to careers in scientific research and in teaching. The survey comments that science education is heading for a crisis not only in the quantity but also quality of persons who want to teach in elementary and secondary schools. Opel (1982) reports that a survey of state science supervisors revealed a shortage of high school chemistry teachers in 38 states, a shortage of mathematics teachers in 43 states, and a shortage of physics teachers in 42 states, including 27 states with a "critical" shortage.

The trend away from science in British schools during the sixties has been well documented (Dainton Report, 1968; Rosenhead, 1968). Dainton (1968), using statistical evidence, shows the gradual decrease in the proportion of science specialists among sixth formers in England and Wales during the sixties. Six years after the Dainton Enquiry, the concern shown by British educators (Duckworth, 1974; Bondi, 1975a; Ravetz, 1975; Williams, 1978) indicates that the problem of the drift from science subjects continues without any significant change. Statistics released by the U.K. Department of Education and Science (1976) shows a continued downward trend in the number of successful O-level science students who are opting for the physical sciences. In other words, fewer students who had passed O-level physics and/or chemistry are willing to continue the same subjects at the A-level. Since 1963 and up till 1974 there has been a drop of around 30 percent in the proportion of successful O-level physics students selecting A-level physics, despite the introduction of the new Nuffield physics programme. A study carried out in 1977 (Pell, 1977) highlighted the fact that there was still a continuing concern about the drift from the science to the arts.

The negative swing does not seem to be confined to England and the United States and is therefore not the result solely of the peculiarities of the British or American educational systems. A swing against the sciences at university level has been noted in the Netherlands and in West Germany (Jevons, 1969: 124). In Australia, a marked decline has been noted (Thornton, 1968-9) in the percentage of students selecting science subjects at the secondary school level and those enrolled for science courses at universities. In New Zealand (Osborne, 1980), a gradual decline in the number of students enrolling for the New Zealand School Certificate in Physics, Chemistry and Biology has been recorded for the period 1969 to 1979. It is quite likely that this decline may have been due to a shift from the single science subjects to a general science subject, namely S.C. Science. Yet it is interesting to note that from 1975 until 1979 there has been a downturn in the relative number of students taking S.C. Science. The trend at the sixth form level also reflects a move away from science subjects, or at least, no renewed interest in the sciences is evident so far. The N.Z.U.E. Chemistry and Physics are struggling to maintain their numbers despite the increase in the number of sixth form students. The state of U.E. Biology has been healthy until 1979 when a slight fall was recorded.

Summary

Some of the pressing problems confronting mankind are: the threat of overpopulation, increasing poverty especially amongst the third world countries, environmental pollution and rapid depletion of limited and non-renewable resources. Developments in the field of science and technology have contributed to better health and welfare for many. However, this progress and various other types of advances, related to science and technology, have not always been universal nor beneficial to mankind or the biosphere. Technological and scientific developments have either aggravated, given rise to or failed to minimise some of these major global problems. As a result, the general public have grown disillusioned with science and technology and this disillusionment is reflected in their attitudes. A significant proportion of the public believe that: scientific discoveries are tending to break down people's ideas of right and wrong, scientific discoveries are making our lives less healthy, and the benefits of scientific research are perhaps tending to be outweighed by the harmful effects.

At the educational level, a relative decline in the number of students continuing their study of the sciences has been noted for the past three decades. There is a growing concern, especially in the United States, about the relative reduction in the number of science and mathematics graduates enrolling for teachers' courses in both teachers' colleges and university departments. There is now a shortage of chemistry and physics teachers in the United States. The reasons for the current situation in science and science education are undoubtedly many and complex. However, one possibility is that an adverse community attitude towards science and technology could well influence the degree of public support for school science, and could also affect students' preference or lack of preference for the sciences. What I intend to do in the following chapters is to argue that there are deficiencies in the current secondary school science education - deficiencies that not only drive students away from school science but also help to foster misconceptions about science itself. Furthermore, I shall argue that school science has failed in helping to forge a new direction for education in science and technology, mainly because it appears to be bogged down in old and no longer acceptable ideas about the nature and function of scientific activities in their real complexity.

CHAPTER TWO

SCIENCE EDUCATION AND THE IMAGE OF THE SCIENTIST

Students' views of the attitudes and characteristics of the scientist influence, to a large degree, their feelings towards science. These, in turn, affect the popularity of science education. It will be argued that textbook interpretation of the scientist is very often a misrepresentation since the image portrayed has little in common with the actual characteristics and behaviours of past and present scientists. I will attempt to show that the stereotyped image of the scientist as found in science textbooks and as imagined by students, has its roots in the manner in which science education portrays science. That is, it is a consequence of the practice of school science to deal only with the products of science. I shall also attempt to show that the textbook image has much in common with the standards of behaviour formulated by Merton and others. These behaviours are generally known as the Mertonian norms of science - norms that are regarded as ideal institutional standards to which scientists need to adhere in order to ensure the rationality and the basic character of scientific knowledge. The norms in question are: communalism, universalism, disinterestedness, scepticism, emotional neutrality, and rationality. Various possible meanings of these terms will be explored in this Chapter. In addition, I shall briefly consider the influence of certain formulations of the Methodological Reductionists. I shall merely provide an outline of the influence of the latter and delve into this at greater length in the next Chapter, when discussing textbook conceptions of 'scientific processes'.

The dangers of students accepting the stereotyped image found in school science, popular literature and the news media are that they may end up believing that scientists and scientific knowledge are neutral, 'objective' and impersonal. The decline in popularity of science subjects will be shown to be partly a consequence of the stereotyped image of science and scientists. If school science ignores the subjective side of the scientist and of his professional i.e. scientific activity, which the thesis will reveal is the current practice, then there is the possibility of another adverse effect. Myths can be easily transformed into reality. Students may come to believe in the cold and impersonal image of the scientist, and they may believe that they themselves ought to behave accordingly. By perpetuating this mythical image of science, there is a strong possibility that science education could produce future generations of robot-like technocrats who relate more easily to a mechanical and impersonal approach to social problems rather than being aware of the place of human emotions and feelings, values and moral considerations, etc. in matters concerning the individual and society. Indications are that such a mentality has already emerged. There is also a strong likelihood that science graduates may, in their own teaching, perpetuate whatever mythical images of scientists they themselves have absorbed during their own schooling.

My intention in this chapter is: (i) to identify some major images of scientists that students hold; (ii) to argue that the actual picture is somewhat different from the stereotyped image one so often finds in science textbooks and in popular accounts of science; and (iii) to discuss some dysfunctional consequences of the stereotyping of the scientist.

The common image of the scientist

The following literature survey lends support to the view that students do widely accept the stereotyped image of the scientist. In a study carried out by Mead and Metraux (1957), it was found that students imagined the scientist to be a man in a white coat who is cold, impersonal, and out of touch with everyday life. A few years later, Beardslee & O'Dowd (1962) found that there had been little change in students' conceptions of the scientist. They noted that American students considered the scientist in the following terms:

> First, the scientist is characterized by high intelligence, dissociated from artistic concerns and sensitivities.... Second, there is a clear lack of interest in people.... [The scientist is] self sufficient, rational, persevering, and emotionally stable.... The personal life of the scientist is thought to be quite shallow.... [He is] a masculine figure in a desexualised way.

Similar findings have been recorded in England by Hudson (1968). He noted that physicists were seen by English students as "dependable, hard[i.e. 'hard-minded'] hard-working, manly and valuable." Novelists "were seen by contrast as imaginative, warm, exciting and smooth" (p.31). Using a Semantic Differential questionnaire[1], Hudson was able to show that mathematicians, physicists, and engineers were closely related in the minds of school boys as cold, dull and unimaginative. Similar findings have been made by McNarry and O'Farrell (1971) in the United States

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1. The Semantic Differential Technique as first developed by Charles E. Osgood and his colleagues (1969) is used to measure the meanings of a concept and comparing them with respect to the meanings of other concepts. In a typical application, a group of subjects is presented with a concept or a number of concepts whose meanings are to be determined. Under each concept are a series of scales bounded at each end by a single adjective. The adjective pairs that comprise each scale are antonyms. There are usually seven places in the scale. The subjects are required to place on each scale a single check mark which best expresses their feeling towards the concept being rated. For example, consider the concept the 'Scientist' which is to be judged on the scale emotional/unemotional:

   Scientist
   emotional: - - - - - - - : unemotional
   1 2 3 4 5 6 7

   If a subject considers the concept 'Scientist' more emotional than unemotional, he/she would check the space 1, 2 or 3. A check in 1 would mean that the subject considered the concept 'Scientist' to be at the extreme end of the emotional side of the scale, and so on.

and by Ashton and Meredith (1969) in England. A later study by Shallis and Hills (1975) reveals some variation in students' conceptions of the scientist but, on the whole, there is a strong evidence of the persistence of the stereotyped image. It was found that:

1. a large percentage of the students imagined the scientist to be cautious, calm and realistic - the neutral image;
2. twenty three percent of the respondents described the scientist in physical terms, as "a white-coated man in spectacles, working in a laboratory"; while
3. nine percent of the respondents mentioned that there were no stereotypes and expressed the view that the characteristics of the scientist cover a wide range of behaviours.

Mackay's (1970) study, involving about 1,200 Australian students of Forms 1 to 4, revealed that scientists as seen by the students:

1. were cold, objective and impersonal;
2. need not be creative; and
3. used the 'scientific method' when they were doing almost anything.

This random selection of studies lent support to the view that students have a stereotyped image of the scientist. Despite emphasis in the existing science curricula upon the structure and processes of science, as basic requirements for understanding the nature of science and scientific practice, the traditional image of 'the scientist' continues to exist in the minds of students.

Scientists' own perceptions

It is suggested that some practising scientists are in the habit of endorsing a particular image of the scientist. For example, Weinberg (1974) found that some scientists have a tendency to practise what they consider to be an essential element of science. They perceive science as being "cold, objective, and non-human. The laws of nature are as impersonal and free of human values as the rules of arithmetic." According to Polanyi (1958: 15-17), scientists attempt to seek at all costs to eliminate from science those elements of man which are deemed subjective. They strive to play down all but an "objectivist framework even though that cannot account for the intellectual powers, passion, and personal and human appraisals of theories". Kuhn (1963) points out that the subjectivity of hard science is often masked. The scientist is so socialised into the assumption that the scientific community knows what the world is like, that he concentrates on completing the picture of the universe. In the process he learns to suppress subjectivity,as he sees it. Ronayne (1976) goes to the extent of criticising the scientific community by suggesting that scientists, knowingly or unknowingly, allow the stereotyped image to flourish by failing to explain to the public the nature and the social implications of their work. In the absence of any enlightenment, the public continue to believe in the mythical images of science and scientists. Furthermore, where scientists themselves have been rigorously schooled in the popular images of science and the scientist, it becomes increasingly difficult even for them to realise the existence of and the role played by the subjective side of science. As Ann Roe (1961) pointed out, many scientists are genuinely unaware of the extent of their personal involvement and so accept the idea of impersonal objectivity. Such a situation raises doubt about the extent to which one can uncritically accept scientists' own words about their practice and about their characteristics. However, it is not universally true that all scientists are unconscious of their personal involvement, and it is likely that there are some whose utterances may reflect this view.

Sources of the stereotyped image

It seems very likely that any science curriculum along with its translation into practice would embody particular images of scientists, of scientific knowledge, and of the relationship between them. These are often explicitly stated, and sometimes they are communicated either implicitly or incidentally. In addition, the mere absence of information on attitudes, beliefs, and scientific practices allows long established myths to remain unchallenged in the minds of students. Very often the picture that students have of the scientist only comes to light when students' responses are examined. Sometimes the intended outcomes of a school science programme do not eventuate. For example, one of the intentions of the PSSC (Physical Science Study Committee) physics project was to help students become aware that scientists are normal and fallible like the rest of us. However, Mackay (1970a) and later Gardner (1973), during an evaluation of a new physics curriculum (based mainly on the PSSC project) in the state of Victoria, Australia, found that after two years of this physics course, students saw scientists as being even less like 'ordinary' people than they had seemed before. This indicates that, despite attempts by authors of science textbooks to improve the image of the scientist, the stereotyping of the scientist still persists. What then could be the cause of the persistence of the traditional view of the scientist?

One possibility is textbooks' treatment of the scientist and scientific practice. Kuhn (1963:347) states that many school science textbooks portray scientists as without prejudice and as collectors of 'objective' facts, especially in the case of traditional science textbooks. An examination of several science textbooks by Cawthron & Rowell (1978) showed that, in the majority of cases, the scientist is often depicted as a "depersonalised and idealised seeker after truth" (p.32). One factor that has a lot to do with the fostering of a particular picture of the scientist is the manner in which science is taught in secondary schools. This is an issue that will be explored more extensively in a later chapter. At this stage it will suffice to mention briefly how teaching of science directly contributes to the image of the scientist held by students. Mead & Metraux (1963:41) observed that "science as it is taught in our schools is largely divorced from life... the scientist is pictured as a man who spends his time in the laboratory, indoors and shut off from life, peering through a microscope or a telescope ... oblivious to the persons around him." The question then arises: Why do science textbooks embody a particular image that is so inadequate and misleading?

One possible reason is that science textbooks emphasise the finished products of scientific activity. This, according to Walters and Boldt (1970), results in the student acquiring a narrow view of the behaviours and attitudes of the scientist. Where a science textbook concentrates on the products of science, it is seen as merely recording the outcomes, discoveries, and confirmation procedures. The objective of the textbook becomes one of providing the reader with a statement of what the contemporary scientific community believes it knows and of the principle uses to which that knowledge can be put. Information about the ways in which knowledge is acquired with their many false starts, changes and frustrations are seldom explained. The student is, therefore, deprived of an insight into the actual activities of the scientist, which if made explicit, would provide a more accurate picture of scientists and their activities. Unless the textbook at the secondary school level is an unusual one, there is very little reference to attitudes like awe of 'nature' (Newton), 'creativity' (Einstein), 'perseverance' (Curie), and 'curiosity' (Darwin) that have been claimed (Taylor, 1966;

Judson, 1980) to be some of the characteristics of scientists.

The current state of affairs is also due to science textbooks following the style of writing that one finds in scientific journals. Scientific journals are very often a source of information for the writers of science textbooks. For example, an examination of the New Zealand 6th form biology text, Biological Science: Processes and Patterns of Life (1973), revealed that 45 per cent of the references cited in just one section alone were scientific journals. It is therefore very likely that the objectification of the observer and the writing styles of scientific journals would tend to be unconsciously incorporated into science textbooks. What is problematic is the mode of communication, the nature of the language used, and the institutional standards maintained by the editorial staff of any one scientific journal. The method of communication of one's findings, appearing in research journals, follows a distinct style whereby personal characteristics and possible failures and false starts of the writer(s) are eliminated. Contributions to journals must conform to the institutional standards laid down by the members of the editorial staff. And the basic norm is that the contributor must refrain from allowing personal characteristics to appear in his writings. Whenever writers of science textbooks use scientific journals as their source of ideas, facts and data, in the process they fail to mention the extent to which personal factors are part of the extremely complex activites of science, as distinct from its outcomes. So the stereotyped image of the scientist, as attested by Medawar (1963), arises from the edited, public science and not from the study of scientists themselves. In contrast to the actual activities and experiences of the scientist, public science, that is, the findings as presented to the scientific community, is devoid of the subjective side of the scientist.

Many would not question the depersonalisation of the scientist's image because it is common to find in the aims of any science curricula a list of scientific attitudes (for example, being objective, neutral, sceptical, rational and so on) that students need to acquire and develop. It is generally maintained that these attitudes are necessary for students to possess if they are to be successful at science (see, for example, Science Forms One to Four Draft Syllabus and Guide, N.Z. Dept. of Education, 1978). Moreover, it is frequently pointed out that these qualities are common amongst scientists, and progress in science is seen as being largely due to scientific communities' acceptance of and adherence to these institutional standards. But is it a fact that the commonly acclaimed institutional standards or norms of science have been crucial in guiding and making possible various discoveries in the field of science and technology?

Before exploring to what extent the above claim is justified, I shall first elaborate on the accepted values or norms which "define standards for the acceptance and certification of additions to the body of scientific knowledge" (Rothman, 1972: 102) and which also provide guidelines to the appropriate approach and methods to be employed. The main body of current thinking regarding the norms of science derives from the works of several sociologists of science, for example, Barber (1962), Storer (1966) and most notably Robert Merton (1957). The thoughts of the latter have undergone several formulations and further additions have been made to the original list of recommended norms of science. However, there are some (e.g. Cotgrove, 1970) who maintain that the Mertonian norms have survived without modification. Disregarding whether or not there have been modifications, norms that one can readily associate with the sentiments of Merton and others appear in popular science accounts and in science textbooks.

Merton (1957) established a set of norms on the basis of evidence taken mainly from statements made by scientists about science. One of the purposes of outlining the norms is to challenge the arguments of those who have attempted to separate the Mertonian norms from the 'irrational'/'non-rational' aspects of scientific behaviour thereby downplaying the importance of commitment, curiosity, expolatory impulsion, hope, stubbornness, etc. to the progress of science. The purpose of this challenge is to show that knowledge of science is hampered if we persist in drawing the boundaries between the two sides too sharply. The following are the norms Merton (1957:553 ff.) considered to characterize the thinking processes of scientists:

Universalism. A fundamental attribute that is said to characterize the scientific value system - it stipulates that the information presented to the scientific community be assessed independently of the character of the scientist who presents the information. Moreover, any scientific statement should be determined without reference to the social, political or national characteristics of the author.

Communality. Another central value is the stress on the communality of scientific knowledge. It requires that the researcher share his/her findings with other scientists freely and without favour.

Disinterestedness. The value of disinterestedness requires scientists to pursue scientific knowledge without considering their careers or their reputations. It prohibits active interest in doing research which would bring prestige or financial success in the lay community; the interest of scientists is limited to research and discovery as an end.

Organised Scepticism. According to this criterion, scientists are expected to be critical of knowledge claims put forward both by other researchers and by themselves.

To this list of norms we can add two other norms formulated by Barber (1962:122-42) and frequently included as part of the scientific attitudes representing behaviours associated with critical thinking of scientists - rationality and emotional neutrality.

Rationality. This relates essentially to having faith in reason and depending on empirical tests rather than to imagination and tradition to substantiate any hypothesis.

Emotional Neutrality. This institutional imperative is prescribed so that scientists can avoid any emotional involvement since personal feelings are believed to distort one's judgement. Besides personal feelings, scientists should not allow non-scientific considerations (religious, ideological, or political) to interfere with their research work and findings. The consequence is that many writers of popular science literature or science textbooks have come to accept these idealistic, institutional imperatives and subsequently their writings evoke images where the scientist is made out to be objective, emotionally neutral, open-minded, etc.. Some argue (for example, Ben-David, 1975:26) that the values formulated by the sociologists of science are necessary for keeping in check the emotions and prejudices of scientists. Subjective characteristics are seen as obstacles to the growth of scientific knowledge. It is also maintained that the prescribed institutional standards help in safeguarding popular respect for science. Science can be seen as socially neutral (King, 1971) because the norms of science are instrumental in preventing scientists from interfering with the neutrality. Proponents of the traditional norms of science, as noted by Price (1963), have been quick in pointing out that advances in the field of science and technology are due largely to the scientific community's acceptance of these norms. They claim that the observed successes in the field of science have been brought about by the fact that scientists are open, uncommitted, and self-critical.

But is it generally true that the criteria set down by Merton and others have been instrumental in helping scientists develop new theories and solve scientific problems? Can it be established that open-mindedness, disinterestedness, objectivity, etc. are in fact inherent or acquired qualities that can be said to identify the scientific community? My contention is that a variety of evidence points to a widespread deviation from the ideals embodied in these scientific attitudes. What is known of the actual behaviour of scientists can be found to be at least partly at variance with the system of values outlined above.

Before undertaking this comparison, it will be appropriate to examine the extent of the influence of some of the philosophical traditions of science associated with Bacon, Locke, Hume and the Logical Positivists on the image of the scientist. Not only does science textbooks' depiction of scientific practice and behaviour indicate an unquestioned acceptance of the Mertonian system of values but it also indicates the influence of some of the more basic tenets of induction and empiricism. Within the traditional framework, knowledge in the form of perceptions or observations or sense-impressions or sense 'data' are 'given' to us from outside the world, without our intervention. The observer is made out to be unprejudiced and disinterested - an abstraction without prior knowledge and expectations. Science textbooks often portray scientists as following a distinctive scientific method of observation in the hope of revealing the 'truth' about the nature of science. In such a situation, the researcher comes to be regarded as a neutral observer. Walsh (1977:40) notes that scientists are regarded as "messengers of nature". This implies that the observer involved in the observation, collection and analysis of data is able to facilitate a way for nature to 'speak for itself'. The validity of the statements uttered by the scientist is regarded as residing in the claim that it is nature that authorises the utterances of the scientist rather than the view that the scientist is merely an interpreter of nature. Science textbooks and popular literature, by lending support to norms considered to characterise the thinking of scientists, reflect either the influence of or uncritical acceptance of the view that the source of all our knowledge is the sense-impressions - a view that denies the interaction between the immediate perceptual experience and the learner's problems, previous knowledge, expectations, anticipations, and so on. As pointed out by Smolicz and Nunn (1975), the current image of and attitudes associated with the scientist are the result of the uncritical assumption of the validity of the empirico-inductivistic interpretation of how knowledge is acquired.

The popular image of the scientist - myth or reality?

One way of determining the validity of the Mertonian norms and the stereotyped images of scientists is to consider the implications resulting from the interaction of science with industry, state and society.

The growth of what Price (1963) calls 'big science' has resulted in increasing dependence upon external money for further scientific research. This means that the centre of the value system of science may have shifted from the 'ideal' Mertonian standards to standards influenced by state policies and industrial priorities. According to Ellis (1969), the support for research by the state and industry has grown to such proportions that the effectiveness of the scientific ethos is largely neutralized. Scientists now conform to a wider set of values. Under state and industry-funded research, secrecy and competition supercede such universalistic scientific considerations as communality and universalism. External pressures of the industry, such as costs and benefits, lead to a redefinition of assumptions underlying the intellectual life of the scientist.

The study of the personal characteristics of scientists is equally revealing. The contention is, that the actual image takes many forms and involves many qualities rather than those circumscribed by the traditional belief system. Holton and Roller (1958) discovered that actual human characteristics are quite different and that one need not even expect to find the traditional scientific ethos amongst practising scientists. Ann Roe (1961) found that personal factors influence a scientist's choice of what observations to make. Personal factors influence perceptions when one is making observations and judgements about when there is sufficient evidence to be conclusive; they also influence considerations as to whether discrepancies between experimental and theoretical data are important or unimportant to their research. The idea of the scientist as an external, completely neutral,etc. observer is therefore difficult to substantiate.

Mitroff's (1973, 1974) study of the characteristics of 40 of the scientists who participated in the Apollo lunar missions is equally revealing. Mitroff looked at the attitudes, beliefs, and scientific practices of these 40 scientists, over a period of three years. Much of his findings show that there is a deviation from the accepted set of values or norms. He noted that the scientists were passionate, irrational, and strongly committed to their pet theories. What this means is that the subjective characteristics play an important role in the formulation of a theory, in one's commitment to a theory, and in the types of tests carried out to support the theory. It was observed that the Apollo scientists would steadily move discussions concerning theories towards highly personal matters. No theory, it was noticed, could be discussed on a purely impersonal basis.

Another interesting behaviour to emerge from Mitroff's study was the extent of scientific bias. Scientific bias, used in a personal sense, means "the tendency of a scientist to possess ... [a strong commitment] to a scientific position, theory, or a point of view that makes it extremely difficult for that scientist ... to modify his position by rational scientific argument and/or evidence" (Mitroff, 1974:63). What usually happens is that the researcher tends to overlook any discrepancies in his/her findings or (s)he tries to fit the observations by adding further statements to his/her theoretical position. Taken to its extreme, personal bias could result in the scientist being so adamant that no convincing argument can make him/her reconsider his/her point of view. Sometimes old ideas persist till the proponents of those ideas pass away. Max Planck(1949) wrote: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (pp.33-34). In some ways, it appears that bias has a role to play in science. Scientists need to analyse and interpret data. To do this there has to be scientists who can argue for both sides of the evidence. Without bias a lot of sides of the argument would never be presented. Mitroff's study also indicates that there is strong emotional commitment among scientists. Contrary to popular belief that commitment and bias are inherently harmful to scientific inquiry and to scientific 'objectivity', it seems that there can be positive benefits. Being highly committed to a particular view of science or having faith in one's own theory (Kuhn, 1957), provides the incentive to try to validate one's position. Kuhn (1957) asserts "that a scientist must believe in his system before he will trust it as a guide to fruitful investigations of the *unknown*" (p.74). This does not mean that advocates of the subjective side of science are suggesting an unqualified endorsement for commitment and bias. It is in the qualifications and restraint on commitment and bias that provide their positive function in science. And it does not mean that science would necessarily be better off for commitment and bias, nor would it necessarily be the better off without them (Mitroff, 1974). "To remove commitment and bias from scientific enquiry may be to remove one of the strongest sustaining force for both the discovery of scientific ideas and their subsequent testing" (Mitroff, 1973: 765).

The notion of a purely objective and disinterested scientist has been questioned by several investigators (Roe, 1961; Gauld, 1973; Hill, 1974; Mitroff, 1974). Mitroff (1974) found little evidence of the disinterested observer. Respondents in Mitroff's study felt that the only people who took the idea of the purely objective and disinterested scientist literally and seriously were the general public or beginning science students. Contrary to popular belief about scientific 'objectivity', (an issue that is examined again in Chapter 3 under 'Objectivity' in Science) it appears that passion for knowledge, idle curiosity, and altruistic concern are commonly found amongst scientists (Taylor, 1966; Judson, 1980).

Quite often science textbooks imply or depict scientists as being rational in their day-to-day scientific activities. The term rational is often understood as meaning "capable of reasoning cogently" (Ryle, 1949). Harris (1981: 193-8) describes rationality as a concept which is held central to the issue of how we are to understand what is done and what is believed by other individuals. According to Popper (1983: 6), to be rational suggests being able to understand the world and others point of view by arguing with others, by criticising the works of others, by being open to criticism and by learning from others. In this sense, rationality (Gauld, 1973) does play a part in the elaboration of hypotheses, in the designing and execution of experiments, in the discussion of ideas and in the appraisal of the contents of a research paper.

Critical and rational thinking is certainly exercised when a scientist judges the products of those with whom one disagrees although the same care may not be lavished on the arguments of scientists whose views are closer to one's own (Kerkut, 1960). However, when an opposing point of view is being appraised it is not always the case that critical and rational thinking prevails. It is quite possible that one's biased point of view, expectations, and beliefs may well obstruct the kind of rational approach that Popper talks about.

There are other reasons why the validity of the norm of rationality is questioned. Laudan (1977: 208) believes that endorsement of rationality leads to acceptance of a mechanical and impersonal process of analysing ideas generated through imagination and curiosity. Laudan is justified in rejecting rationality since his interpretation appears to suggest an empiricist view of rationality. The empiricist sense-experience has been regarded as the basis of rational authority. According to most empiricist views (Bartley, 1964: 112-4), a rationalist derives all his/her knowledge from sense observation, stopping the infinite regress of demands for justification. Sense observation is believed to be manifestly true, incorrigible and unable to be challenged. For the empiricist, anyone who holds beliefs that could not be derived from clear and distinct ideas is regarded as an irrationalist. It is in this sense that many find rationality to be toally unacceptable. They are critical, according to Kekes (1976), because they believe that empiricist rationality leads to views that are rigid, arbitrary, dogmatic, cold and unimaginative. The charge made by critics is that rationality denies the rightful place of feelings, imagination and creativity. It handicaps the exercise of that "negative capability" (Kekes, 1976: 7) which renders us receptive to the mysteries, ambiguities and uncertainties of existence. The failure to acknowledge the role of subjective characteristics in the acquisition and substantiation of scientific knowledge means that an analysis based upon the empiricist rationality would be inadequate. It would be inadequate because such an approach ignores those very qualities that are crucial to scientific progress. For Popper (1983), irrationality does play a part in the construction of hypotheses and theories. Popper (p.28) uses the term irrationality in the context that "we have sources of knowledge other than reason and observation - for example, inspiration, or sympathetic understanding; or tradition, which is perhaps the most important 'source of knowledge'". He suggests that irrationality, within his definition, should be encouraged because ideas so derived can be later submitted to a rational scrutiny. He rejects the irrationalist's argument that any knowledge, of whatever kind, or source, or origin is above or exempt from rational criticism. In addition, Popper (1981) holds that if the individual scientist ever becomes objective and rational (in the empiricist sense), it is quite likely that revolutionary progress of science will be greatly weakened.

The effectiveness of the Mertonian norms of rationality, openmindedness and emotional neutrality as guide to productive scientific behaviour is further undermined by historical examples of the attitudes of scientists. The degree of resistance, stubbornness, jealously and rigid commitment witnessed amongst scientists has been recorded by many investigators. Max Planck (as cited by Barber, 1961) had written the following complaints about some of the practices of members of his scientific community:

> I found no interest, let alone approval, even among the very physicists who were closely connected with the topic. Helmholtz probably did not read my paper at all. Kirchhoff expressly disapproved.... I did not succeed in reaching Clausius. He did not answer my letters and I did not find him at home when I

> tried to see him in person at Bonn. I carried on a correspondence with Carl Neumann, of Leipzig, but it remained totally fruitless (p.596).

Such behaviours of scientists contradict the generally accepted picture encountered in science textbooks and in popular literature. Several other examples are provided by Barber (1961) to support the claim that scientists have intense commitment and exhibit qualities that cannot be adequately explained merely on the basis of the scientific ethos conceptualised by Merton and others. For example,

1. Helmholtz's own writing, Barber cites, reveals resistance amongst scientists especially if the work is seen as undermining their own view of nature.

2. Arrhenius's theory of electrolytic dissociation met with resistance for a time because his theory clashed with the more dominant theories of that time.

3. Lord Kelvin regarded the announcement of Rontgen's discovery of X-rays as a hoax and also resisted Rutherford's theory of electronic composition of the atom.

Such examples of scientific behaviour are rarely recounted in science textbooks and consequently students are deprived of a more balanced picture of the scientist.

Several studies in the sociology of science (Merton, 1957; Barber, 1962; Storer, 1966) have attempted to establish that progress in science can only be assured if scientists discipline their activities according to a set of norms. Studies carried out by Mitroff and others reveal a widespread deviation from the ideals embodied in the Mertonian scientific ethos. Mitroff suggests that a case can be generalised beyond the particular Mertonian norms of science. In other words, a case can be made for the existence of a set of corresponding counter-norms. This does not mean adherence to either the extremes of the counter-norms or the extremes of the institutional norms. This study supports the contention of Cowan (1965) and of Mitroff (1974) that any sensible account of science must not only account for the rational in man's nature but also for the irrational and the non-rational.

Implications of the images and characteristics of scientists

The unquestioning acceptance by science students of the image that scientists must be passionless observers, unbiased by emotion, intellectually cold, etc. has several consequences. For example, the choice of a subject or a career is determined, to a large extent, by students' view of the scientist (Bradley & Hutchings, 1973; Medawar, 1979). Where a scientist is perceived as being cold, objective, and impersonal then such a view has a negative effect towards science and the scientist. Sometimes this leads to an anti-scientific attitude (Mitias, 1970). Hudson (1967) and Dainton (1971) have both found that one of the factors responsible for the drift from science is the stereotyped image of the scientist promulgated by science education.

Another consequence of the common view of the scientist as an unobstrusive observer, questing after objective knowledge by observation and analysis is that such an image, according to Layton (1973), leads to the fostering of a withdrawn, stunted, and mechanized view of the world. In other words, the depersonalisation of the scientist influences the student to conceptualize and analyse the world in a mechanical fashion. The success in the field of science and technology is often attributed to the supposedly dispassionate method of observation, analysis, etc. utilised by the scientist. This has so impressed many social scientists and others that they have embarked on an analysis and interpretation of human affairs in a similar fashion. Such a trend towards objectivity is seen by some (for example, Andreski, 1972) as not feasible because an emotional involvement may prompt untiring curiosity. If writers are to purge themselves of any emotional involvement when analysing any social system then it could result in the wiping out of curiosity - an important incentive for understanding the world.

It is also possible that an intellectually cold and depersonalized image of the scientist, as endorsed by school science, may appear appealing to certain types of students, e.g. the convergers (Hudson, 1968). Inevitably, those who are attracted to such a mechanised view of the scientist could well transform such an impression into reality. The implications are that, as future practising scientists and science teachers, they can become instrumental in the perpetuation of misconceptions about science and scientists. It is worthwhile to note that students do attempt to emulate the mythical characteristics of the scientist. Eiduson & Beckman (1973) found that young people who are thinking of taking up science as a career see scientists in terms of an image which is attractive to them and by which they try to mould themselves. For humanity, it is of little comfort to contemplate that science teaching and developments in science and technology could be in the hands of those who may well relate to humanity and human affairs in a purely mechanistic and depersonalised manner.

Another common effect that the mythical image helps to create is an aura of awe and secrecy because the objective qualities attributed to scientists separate them from the layman; it further lends support to the belief that science is an autonomous activity because the agents of science are seen as neutral and objective investigators. Consequently the product of their activity could not be evaluated on a subjective basis. In this way, the objectivity myth protects the activities of scientists from external criticism since, if research practices are conceived as being objective and 'rational' (in terms of the empiricist view) then criticisms on the grounds of personal bias, beliefs, and commitments are considered irrational. As such, very little criticism can be made. If it is to be maintained that those involved in scientific activities are objective and 'rational', then such a view becomes the easiest line of defence against critics of certain scientific and technological practices.

Summary

The picture of the scientist that emerges from the studies referred to and arguments presented in this chapter is greatly at odds with the textbook image. It differs with respect to the gross features and with respect to the substantial details as well. What the studies reveal is nowhere near what textbooks prescribe. Hence textbooks do not provide an accurate description of the accounts of the scientist or at least not for the samples referred to in this chapter. The traditional norms of science appear to be too idealistic. Scientists do not always abide by a rigid set of institutional imperatives. Even if they do, their personal characteristics do influence their approach to work. The traditional picture is inadequate for an understanding of the nature and spirit of actual scientific life. The effect is that students come to accept science and scientists as cold and mechanical. This, in turn, contributes to a decline in the number of students electing science subjects. 'Divergers' who tend to identify themselves more easily with such ideals as creativity, imagination, intuition, warmth, etc. are repelled by science as presented to them. It is possible that the nature of science education is such that it is attracting those who are too rigid and inflexible for good research. Unfortunately, it is the divergers with their intellectual flexibility that both science and technology so badly need.

In the following Chapter I shall attempt to show that the concept of 'science processes' and the accompanying images of science inherent in secondary school science reflect a commitment to and/or an acceptance of some of the philosophical traditions of Bacon, Locke/Hume and the Logical Positivists.

CHAPTER THREE

THE INFLUENCE OF CERTAIN TRADITIONAL PHILOSOPHIES OF SCIENCE ON SCHOOL SCIENCE

During the past twenty years curriculum development and instruction in science education have been built around what had seemed to be the most promising theories or models of learning. Of these theories, Bruner's 'discovery learning' and Gagné's conception of 'science processes' have had considerable influence. These works provided the impetus for a redefinition of the content and objectives of school science in terms of the structure of the disciplines and the processes of scientific enquiry. It was assumed that scientific processes were underlying and generating the content of science. In addition, emphasis on process skills via the 'enquiry' or 'discovery method' became the central theme of curriculum development in science education. This was seen as the cure for the stigma of excessive rote learning of disconnected fragments of scientific knowledge. Educationalists not only considered these learning theories as useful for a better understanding of science and scientific activity but also as necessary for facilitating greater student involvement in classroom activities. The student could now have more opportunity to participate in the learning activity, i.e. to question, to do rather than 'see' experiments, to test ideas and to think for him/herself. However, such learning theories lacked well-developed methodological starting points since the 'methods' of science, scientific 'principles', science concepts, etc. were left unexamined. It appears that science educators and curriculum developers failed to examine their methodological starting points and/or assumed the commonly held views of the nature of science were adequate and correct (Hurd, 1982). In the opinion of Stenhouse (1972), many of our present deficiencies in science education stem from decades of neglect of the essentially methodological and/or philosophical issues.

In other words, one of the reasons for the continuing crises in science education is that there are weaknesses in the current structure and process of science education which have been brought about by a failure to take into consideration questions about the nature and function of science. It is also possible that science educators' preference for the concept of 'science processes' developed by educational psychologists, has been influenced by pedagogic convenience rather than any scientifically- or philosophically-induced reasons.

In this Chapter, I shall examine the epistemological roots of the conception of science and science processes in order to determine if the view of science presented by school science is compatible with the system described by contemporary philosophers of science. My contention is that the current image of science that school science projects is inadequate and misleading. This will be shown to be a consequence of the influence and absorption of some of the basic assumptions and tenets of the philosophies severally of Bacon, Locke/Hume and the Logical Positivists(Layton, 1973; Smolicz & Nunn, 1975; Brush, 1976; Cawthron & Rowell, 1978; Jenkins, 1979; Finley, 1983). ['Logical Positivists', using initial capitals, may suggest a reference to a more determinate group and set of doctrines than is always intended. However, it seems best to use the 'over-determinate' designation to serve as a base-line, mentioning specific deviations only where relevant.] I shall attempt to reveal some weaknesses inherent in these particular traditional conceptions of the nature of science. I shall consider some of the outcomes of the often unsuspected and perhaps even unconscious commitment to the traditional view of science. These are:

(i) that induction is the only valid scientific method;

(ii) that the growth of science is cumulative;

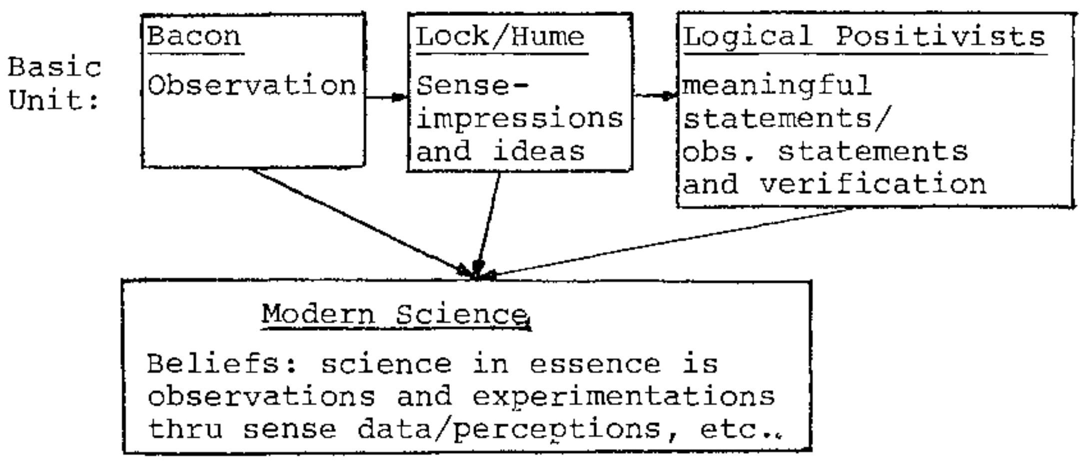
(iii) that discoveries in science have in fact been made by the processes of induction and empiricism; and

(iv) that science is essentially objective.

These images of science and the historical interpretation of progress in science will be shown to be unsupported by current findings and writings in the philosophy and history of science. I shall discuss some of the tenets of the philosophies of Bacon, Locke/Hume and the Logical Positivists which I believe have had a profound influence on science educators, curriculum developers and educational psychologists in terms of their conceptions of the nature of science.

Certain Traditions of the 'Methodological Reductionists'

I shall collectively identify the basic tenets of Bacon, Locke/Hume and the Logical Positivists as the tenets of the 'Methodological Reductionists'. Our understanding of the nature of science reflects some influence of the tradition of science attributed to Bacon. The 'Baconian' theory of science (Brush, 1976) also known as the "inductive" method suggests that the way to do science is to collect a large number of observations and experimental findings about a subject and arrange them systematically. One may then formulate a hypothesis to explain the data, but it must be tested by further experimentation.



Generally speaking, in terms of the Baconian theory, all reliable knowledge comes from observation. Theories can be developed only after enough facts are established. Theories in the Baconian sense are not mere conjectures open to refutation but established conclusions about certain scientific phenomena. The inductive method suggests that science is a quasi-mechanical technique for collecting and analysing objective facts where the observer is passive. The observations made are passively received by the mind and there is no reaction between the observations and the observer's prior knowledge. It is also held that inductive procedures - an 'inductive logic' - are adequate justification for our theories. In other words, Bacon and other inductivists believed that any inductive inference - any reasoning from singular and observable cases (and their repeated occurrence) to anything like regularities or laws - must be valid.

Locke's work (and that of the empirical school in general), according to Harris (1969: 169), refused to accept knowledge on authority and appealed to experience for the validation of beliefs, yet it maintained, in essence, the primacy of observations and experimentations. Locke put forward the view that all knowledge comes from *experience* and that none of it is in the mind. It was pointed out that we begin with 'ideas' and these we acquire in the first instance through the senses and in the second from reflection on the operations of our mind. The original source and the first beginnings of knowledge starts with

(a) 'simple ideas of sensation' - direct sense experiences e.g. smell, taste, sound, etc.; and

(b) 'simple ideas of reflection' which are products of introspection i.e. the awareness of the workings of our minds.

Locke's idea fosters a belief in the passivity of mind.

In other words, during the receipt of simple ideas the mind is wholly passive. The same view is implicit in the ideas of Bacon. The mind cannot make, distort or destroy the ideas it receives. However, the mind can repeat them, recall them, combine them, and so on. The results of these operations are complex ideas.

In line with Locke's theory of the source of knowledge, Hume (Hospers, 1967: 102) also considers all ideas as originating from experience or perceptions:

(a) some through the 'outer' senses such as sight, hearing, touch, etc.; and

(b) some from 'inner' senses, such as experiences of pain and pleasure.

It can be noted that Locke called the first: ideas of sensation and the second: ideas of reflection. The main essentials of the position laid down by Locke and taken over intact by Hume (Harris, 1969: 237-8) are the classification of ideas into simple and complex. This is retained and likewise the distinction between ideas of sensation and those of reflection. Hume went further in making a clear distinction among experiences or perceptions, between "impressions" and "ideas". Impressions were said to be the immediately apprehended presentations, e.g. if I see a green tree I have a green *impression* (sense-impression). Ideas were the 'paler' copies of those revived in memory and imagination e.g. if I close my eyes and imagine some observable object then I have an idea of that object. According to Hume (Hospers, 1967: 112), every word or phrase must be traceable to sense-experience in some way, whether the route be through impressions or ideas.

The phenomenalistic doctrine implies that "all our knowledge, all our belief and all our conjectures begin and end with experiences; that we cannot go behind or beyond these" (Passmore, 1980: 89-90). Hume was not a phenomenalist in this sense of the word but he was a phenomenalist, however in a narrower sense. He argued (Passmore, 1980: 90) that "we could not know anything but 'perceptions' in that restricted sense of 'know' in which it means be certain of, without any risk of error, nor can we even infer by any sort of 'probable reasoning' that anything else exists." It is noteworthy that Hume's criterion of meaning that every word or phrase must be traceable to sense-experience, together with the positivistic principle of verifiability have had some influence on the formulation and use of operational definitions of concepts in science education.

The theories of knowledge presented by Bacon, Locke and Hume have many features in common. One of these is that they consider all concepts derivable from sense-experience and all deduction only a matter of comparing ideas from sensation and reflection. In varying degrees, they believe in the inductive method as a method of analysis for justifying scientific generalisations. However, Hume's position is that arguing from experiments and observations by induction is not *valid* reasoning. He points out that no matter how many particular premises we accumulate, the transition to a universal conclusion is fallacious. Yet he maintains that the transition from occurrences of a particular event to universal conclusions is acceptable with a proviso that it is more psychology than logic (Passmore, 1980: 58). The suggestion is that the aggregation of positive instances constitutes the difference between probability and proof; at some point the number of instances is so large that together they constitute empirical proof. Thus Hume converted logic into psychology (Passmore, 1980: 58; Popper, 1983: 31-3).

Another philosophical tradition that has had influence on science and science education is that of the Logical Positivists. Logical Positivism which is also called "logical empiricism" developed in Austria and Germany in the 1920s by a group of philosophers, scientists and mathematicians, whose leading members were Schlick, Carnap, Waismann and Neurath. The movement was never marked by unanimity of opinion and this needs to be borne in mind when the expression "logical positivism" is used. I shall point out the main tenets of their philosophical position. The logical positivists were marked by a great hostility toward metaphysics (Achinstein & Barker, 1969). However, it was not only what they perceived as the detrimental influence of metaphysics on philosophy that was decried. The logical positivists (Phillips, 1983) wanted to expunge it from science as well. To them, it appeared that physics (e.g. Einstein's special relativity theory) had drifted far from experimental and observational facts. They were determined to rescue 'objectivity' in science by finding a definitive basis for resolving scientific disputes.

They adopted the verifiability principle of meaning, which stated that something is meaningful if and only if it is verifiable empirically (i.e. directly or indirectly by observation via the senses), or is a tautology of mathematics or logic. Thus significant propositions or statements were divided into two classes: formal (analytic) propositions of logic or pure mathematics and synthetic propositions (i.e. those purporting to convey information about the world). This division was applied to science which the logical positivists saw, not as a system of concepts, but rather as a system of statements. Empirical statements were meaningful if their truth or falsity could be determined by actual or possible observation. This implied that the truth of an observation was always manifest to a careful observer. Such a position excludes the influence of the individual's own theories and expectations. The observer is therefore turned into some sort of abstraction. The verifiability principle had a stormy history, and it went through a number of changes in attempts to insulate it against the well-founded criticisms it provoked (Phillips, 1983). For example, the statement that all meaningful statements are verifiable is itself not verifiable.

The logical positivists were faced with the problem of providing an answer to the question: What will count as a satisfactory explanation of the verification procedure in any given case? They resorted to a class of elementary "observation statements" (Phillips, 1983: 5). A given term could be validated and hence given meaning if it could be connected to direct and indubitable descriptions of sense-experience. There were, however, theoretical entities, like the entities postulated in sub-atomic theory, which are not directly observable; and even indirect confirmation is a complex business. The rigorous use of the verifiability principle of meaning poses a problem here. To overcome this problem, Ayer (1976a) stated that such theoretical entities could be thought of as "simply as conceptual tools which served for the arrangement of primary facts" (p.110). Thus scientific theories could not be true or false, but as tools they could be economical, useful, or instrumentally helpful.

The central assumptions of the 'Methodological Reductionists' are: (1) that man, in his perceptual experience, encounters a world that exists independently of his beliefs and theories - that is, scientific knowledge is not dependent on man's cognitive or other states of mind; (2) that by means of sense-perception and interpretations based upon perception, it is possible to gain knowledge of this independently existing world; and (3) that observation or sense-experience and the inductive procedure provide the ideas for the formulation of hypotheses and theories rather than that hypotheses and theories determine what is perceived and dictate principles of truth and validity. In Chapters 3 and 4 I shall explore the extent of the influence of these assumptions upon science education.

<u>Conception of 'science processes'</u>

Science texts in use in secondary schools have been designed to support, among other concepts, science as 'enquiry' and investigation. These are common to most science teaching and are related, in varying degrees, to Gagné's idea of science processes (Strike & Posner, 1976; Finley, 1983). To understand Gagné's view, it is necessary to look at what is meant by the 'scientific enquiry'. Gagné (1963) describes enquiry as

> a set of activities characterized by a problem-solving approach in which each newly encountered phenomenon becomes a challenge for thinking. Such thinking begins with a careful set of systematic observations, proceeds to design the measurements required, clearly distinguishes between what is observed and what is inferred, invents interpretations which are under ideal circumstances brilliant leaps, but always testable, and draws reasonable conclusions (p.145).

Gagné maintains that students must have a great deal of conceptual knowledge in order to be able to make inductive inferences (deriving a generalised statement from a collection of particular statements) and to judge whether those inferences are valid. To acquire this prerequisite knowledge, he suggests that students need to develop certain capabilities - the process skills. The sequence of the process skills, commonly known as the learning hierarchy consists of the processes of observing, classifying, describing, communicating, measuring, recognising, and using spatial relations; drawing conclusions; making operational definitions; formulating hypotheses; controlling variables; interpreting data; and experimenting (Gagné, 1970). It is not uncommon to see these skills emphasised in modern science curricula.

In Gagné's hierarchy of learning, observation is seen as the fundamental skill by virtue of its position as the foundation of the hierarchy of skills. Consequently, it implies that knowledge develops inductively from observations or sensory experience. Such a belief has been part of the tradition of science education even in the past. For example, Layton (1973: 58-9), in tracing the history and development of science curriculum, noted that even in the 1800s when science was being organised and initiated in schools, inductive thinking had already appeared. It was accepted that observation was the fundamental skill necessary for the acquisition of meaningful knowledge. It was also assumed that anything happening a great many times could be treated as a basic fact upon which a firm piece of knowledge could be established. The existence of this particular view of learning processes in science teaching has also been pointed out by Margenau (1967), Jevons (1973), Brush (1976) Warmer (1977) and Cawthron and Rowell (1978).

Science textbooks of the sixties and seventies show the extent of the influence of the tenet that knowledge develops inductively from sensory experience. The Nuffield Science Teaching Project stresses the teaching of science as an enquiry and encourages pupils to think about scientific things in the way that practising scientists do (Jenkins, 1979: 67). And scientists were seen as making rigorous observations and inferring from these observations. The CHEM Study text (1963: 2) rules that pupils should follow a prescribed pattern of observation, search for regularities and then search for explanations in terms of models. Jones (1978) in his text, Chemistry, Man and Society, states that "chemistry begins with observations and experiments" (p.3) and "a scientific law summarises a large number of related facts" (p.11). Layton (1973a), in his study of the nature and processes of science portrayed in the 'first generation' science projects (PSSC physics, BSCS biology, CBA chemistry, and CHEM Study) and Cawthron & Rowell (1978) in their examination of various science textbooks, found that textbooks were concerned with putting the student in the position of a scientific enquirer where the practitioner was seen as being involved in collecting facts, interpreting these and then formulating some general statements. Without regard for their prior knowledge and experience, students were encouraged to see a governing process that makes them 'scientists' and their efforts 'scientific'.

It appears that the methodological premises upon which the school science conception of 'science processes' is based are induction and empiricism, i.e. Gagné's conception of science processes reflects an acceptance of induction and empiricism as the legitimate underpinnings of scientific enquiry. This relationship becomes evident when one examines the tenets of induction and empiricism as formulated by the Methodological Reductionists.

The concept of induction

Induction refers to any method for verifying or showing to be true general laws on the basis of observational data (Putnam, 1981). This inductive method based upon observations was first systematically formulated by Francis Bacon. Although his formulation has been qualified, added to, refined and sophisticated since his day, something in the tradition he pioneered has survived till the present time. The basic tenets of induction are that scientific enquiry consists of four stages:

1. the scientist begins by observing and collecting data,
2. facts are then analysed and classified,
3. with the growing accumulation of facts, general features begin to emerge and hypotheses are derived from a generalization of the facts, and
4. the scientist then carries out further tests in order to confirm the hypotheses.

Generalised statements, once confirmed, are regarded as lawlike because they fit all the known facts, and explain how they are causally related to each other.

The present view of science processes has much in common with the inductive method. For example, Gagné (1963) describes scientific enquiry as a matter of solving problems by "unrestrained inductive thinking" (p. 153). In addition, his description of the learning hierarchy resembles Bacon's tenets of induction. Both contend that general laws can be developed and verified on the basis of reliable observational and experimental data. Textbooks place a high degree of emphasis on observations and experiments but offer little guidance on what observations to make and how they are to be interpreted. This practice is probably due to acceptance of the traditional explanation of how scientists did their work. The Methodological Reductionist view stipulates that ideas are formed from individual sensory impressions (Hume, 1974) and that facts are collected independent of any theoretical influence. Ernst Mach (in Taylor, 1966) stated that individuals must have an absolute respect for observations, that is, individuals must hold scientific theories in judicial detachment when making observations. For, to have preconceived ideas would mean introducing bias, thereby jeopardizing scientific objectivity. The Methodological Reductionists consider complete personal detachment necessary for collection of data because the data can then provide a basis for validating a generalised statement.

The concept of empiricism

The other part of the Methodological Reductionist premise that has had an impact on science education is empiricism. Empiricists, such as Locke (Hanfling, 1981:6), maintained that all our knowledge comes from 'sensation' - something that happens to us when we use our eyes, ears, noses and so on. Hume's (1974) description of empiricism is as follows: all perceptions of the mind can be divided into two classes, called 'impressions' and 'ideas'. Impressions can be interpreted as the direct sensations received by the senses and are the basis of all knowledge. Simple ideas are images of these sensations that remain after an impression has occurred. Simple ideas are then combined into complex ideas. Hume believed ideas and impressions to be components of experience. From ideas, subsequent knowledge statements or terms or propositions are derived. The meanings of propositions are grounded in experience and there is a distinction between 'theoretical terms' and 'observational terms'. Theoretical terms can be interpreted on the basis of observation. An observation term is only meaningful and true if the impression upon which it is founded is actually observed. Science textbooks' view of science processes is consistent with the early empiricists' view that knowledge is inferred from sensory experience. It is maintained that observation via the senses is the fundamental skill necessary for detecting the characteristics of objects. The fact that Gagné, and subsequently many other science educators, considered observation as the source of theoretical terms or ideas from which broad principles are formed, is indicative of the influence of the empiricist notion of science. In his text, The Conditions of Learning, Gagné (1970) proposed that learning science concepts proceeds from discrimination of the characteristics of objects and events to the formulation of concepts. Observation and discrimination of events are grounded upon the sensory impression and from these processes, conceptualisation can then take place. There are sufficient grounds to believe that the view of scientific enquiry found in science textbooks is consistent with the methodological reductionists' interpretation of how scientific theories are formulated. The traditional idea is held to be inadequate and an examination of recent developments in the philosophy of science will help to highlight the weaknesses.

Inadequacies in the 'Methodological Reductionist' rationale

According to the Methodological Reductionists, theories are verified if they are derived from a finite class of observations. Schlick (1959: 88) maintains that "verification (of scientific theories) is *logically* possible" provided the scientist rigorously applies the inductive logic. It is true that later-day positivists would regard such a claim as naive. Even Rudolf Carnap (1962) conceded that the system of inductive logic and confirmation of a theory is totally inadequate for dealing with the more important episodes in the history of science. However, in the opinions of Rodger (1971), Bhaskar (1975) and Phillips (1983), the verification principle in the strong sense still lingers on, as an implicit assumption in much that is said about philosophy. In terms of man's view of the world, the verification principle has given rise to a widespread practice of maintaining that verification of 'ideas' can be achieved via the senses. In school science, a similar assumption is evident. Mackay's (1970) study involving about 1200 students from Australian high schools, revealed that there was insufficient understanding of the role of theories and their relationship to research and to facts. Students believed that science was largely concerned with the collection of facts and that theories were mere summaries of experiences. Verification of theories was seen as being dependent upon careful collection of observations and meticulously carried out experiments.

David Hume (in Perkinson, 1978) argued that induction is not valid - empirically or logically. The empirical objection is that universal statements or theories refer to the future as well as the past and present. If, according to the inductivist, theories are merely summaries of observation statements, then they are incapable of predicting future events. Theories have predictive value and thus it is empirically not possible to verify, as true, a theory on the basis of observations nor is it possible to formulate a theory merely by interpreting a set of observations.

The logical objection to the inductive method is that no number of singular observation statements, however large, would entail an unrestrictedly general statement. Instances in the history of science show that scientific theories were not formulated from summaries of observation statements nor were they verified on the basis of a collection of facts. For example, Einstein (Magee, 1975) theorized that light must be attracted to massive bodies. That is, light which travels close to the sun on its way from a star to the earth must be deflected by the gravitational pull of the sun. Normally in daytime, it is not possible to see such stars because of the sun's brilliance. But if it were possible, the deflection of light rays would make the stars appear to be in different positions from those they are known to occupy. The predicted difference could be checked by photographing a fixed star during the day if possible, and then again at night when the sun was not there. The theory of Einstein's was highly predictive and open to refutation. It was neither a summary of observations nor was it derived inductively. Its corroboration in 1919, during a solar eclipse, when it became possible to photograph the stars, substantiated the theory. Similarly, Einstein's special relativity theory (Ackermann, 1976) was assumed rather than proved by experimental evidence that various transmissions of light rays had equal velocity as measured in different frames. We cannot apply inductive logic to Einstein's theory. Carnap (1962) pointed out that "to find a numerical value for the degree of confirmation of ... /Einstein's special theory of relativity/ ... as an application of inductive logic is out of the question" (p.243).

Having found that induction was not valid, logically or empirically, Hume attempted to justify its validity on a psychological basis. He argued that repeated instances of a particular phenomenon are sufficient grounds for formulating a theory and also for verifying it i.e. the method of induction by repetition is claimed to provide a standard of justification. According to Hume, it is also acceptable to consider all future instances to be like those observed so far. To accept this psychological basis for the confirmation of a theory, in the opinion of Karl Popper (1959), is to admit that a scientific theory can never be absolutely certain. But this is not what the inductivists would admit to. It therefore appears that the traditional explanation of how theories are formulated and verified is inadequate. In addition, to offer a psychological justification for scientific theories places pure science alongside spiritualism, astrology etc.. There is yet another problem. This concerns the following steps of the inductive method:

1. observation and the collection of facts;
2. analysis and classification of those facts; and
3. inductive generalizations from the facts.

The first step implies that all facts should be collected without the use of *a priori* hypotheses lest the objectivity of science be threatened. If a scientific investigation were to proceed in this way there would be no basis for determining which observations are relevant and when sufficient facts have been collected. The traditional view, as explained by Shapere (1966) and Kordig (1971), implies that there is an absolute, theory-independent distinction between theoretical terms and observation terms. This means that the mind registers objective reality via the senses and that there is no reaction between the sense observation and the observer's expectations, prior knowledge, etc.. The inductive theory does not acknowledge that one's expectations influence what observations are made and how they are interpreted. Modern philosophers of science (Hanson, 1958; Kuhn, 1962; Feyerabend, 1965; Scheffler, 1967; Popper, 1972; Toulmin, 1972a) have pointed out that all perceptions are dependent upon prior hypotheses, theories, judgements, etc.. Different people will 'see' things differently depending upon their entire, past behavioural and physical history, their current emotional states, their feelings, and their aspirations. Feyerabend (1965) states that "the meaning of observation sentences is determined by the theories with which they are connected. Theories are meaningful independent of observation; observational statements are not meaningful unless they have been connected with theories .... It is therefore the observation sentence that is in need of interpretation and not the theory" (p.213). Contrary to the inductive view, it appears that observations and interpretations are inseparable. N.R. Hanson (1967) put it as follows: "Scientific observation and scientific interpretation need neither be joined nor separated. They are never apart, so they need not be joined. They cannot, in principle, be separated, and it is conceptually idle to make an attempt. Observation and interpretation are related symbiotically so that each conceptually sustains the other while separation kills both."

The theory-laden view of observation not only reveals the weaknesses in the inductive theory but also helps us understand why students often interpret things differently from their teachers. For example, consider the following learning situation. A student, who has no prior knowledge of the internal structure of a leaf, examines a transverse section of a leaf under a microscope. He may be able to observe certain shapes, and dark and light patches. He may select from the information stored in his mind some explanation for his observations or his prior knowledge and expectations will influence what he observes. In the absence of the required knowledge, the meanings he attaches to what he sees would often differ from that of the teacher's. Without prior expectations, within the required context, observations would be meaningless. School science, while emphasising the primacy of observations and external knowledge, neglects to give due cognizance to the fact that the learner brings along to a learning situation, his own experience, ideas, and a common sense view of the world. These react in different ways with sense-perceptions. The following study further underlines the type of problem confronting teachers.

The study, titled, <u>The Learning in Science Project</u>, currently being undertaken by several science educators of Waikato University (Tasker, Freyberg & Osborne, 1982; Osborne, Freyberg, Tasker & Stead, 1982; Osborne, 1983), is looking at some of the problems and inadequacies of present day science teaching. Their findings reveal that: (i) children find scientific ideas and theories difficult to understand; (ii) they have strong views about how and why things behave as they do; and (iii) teachers fail to realise that children think in different ways. One of the possible reasons for this type of problem is the influence of or unconscious commitment to certain beliefs and assumptions of the Methodological Reductionistic doctrine. These assumptions and beliefs overlook the role of the student's prior knowledge on novel 'ideas' and 'impressions'. The assumed passivity of the learner's mind and the assumption that prior to formal teaching the learner has no knowledge of a topic (Fensham, 1980) are taken for granted and yet the problems encountered by science teachers are often a consequence of the failure to recognise that, in general, the passive/empty mind does not exist. In other words, teachers fail to recognise that the learner brings prior knowledge and beliefs to a learning situation, that this knowledge and beliefs are invoked whenever the learner is required to make some observations, and the meanings he/she attaches to the observation terms are dependent upon the ideas he/she possesses (also see Gilbert, Watts & Osborne, 1982).

Another point of interest to the teaching and learning of science is the confusion resulting from a belief in induction by repetition as a means of learning. Everybody seems to believe in induction (Popper, 1983: 35), that is, we learn by repetition of observations. Even Hume, in spite of his discovery that a natural law can neither be established nor made 'probable' by induction, continued to believe firmly that we do learn through repetition: through repeated observations. And he upheld the theory that induction, though rationally indefensible was nevertheless reliable; and that 'experience' was the result of an accumulation of observations. The situation exists now where the role of observation and repetition in the learning process has been overstated. Learning has become equated with repetition. This interpretation, according to Popper (1983), has become a serious source of the failure to distinguish among three entirely different activities which are called 'learning'. These are: learning by trial and error, learning by habit formation (or learning by repetition proper) and learning by imitation.

Science education appears to have accepted the common belief that learning by repetition is the most important way of learning. According to Popper, it is only learning by trial and error which is relevant to the growth of one's knowledge. It alone is 'learning' in the sense of acquiring new information. This kind of learning is not the repeated impact of the observable on our senses which leads to a new discovery and new ways of knowing. Learning by repeated observation of a particular occurrence is not learning in the sense that no new ideas or knowledge are acquired. Repetition is necessary when effective learning has not taken place or when there is an element of doubt concerning a particular learning outcome. Learning by repetition is probably more appropriate in the acquisition of psychomotor skills e.g. learning to ride a bicycle. Learning by imitation is probably one of the more primitive forms of learning although from the point of view of the learner, it is a typical trial and error process (Popper, 1983). A child tries to imitate his/her parents and either corrects him/herself or is corrected by the parent. Teaching often fails to encourage students to learn from their errors rather it tends to discourage students from making mistakes. Regular criticism directed at students who make mistakes can only help to stifle their confidence in independent thinking and discourage them from learning by means of trial and error.

When the current tradition of 'science processes' is subjected to methodological criticism, it becomes apparent that two of its tenets - induction and empiricism - are inadequate and misleading. In terms of science education the existing methodological framework of 'science processes' exacerbates the problems of a better understanding of science. Furthermore, induction becomes a source of confusion about how learning takes place. Now and later in Chapter 4 I shall discuss some of the beliefs about science and scientists fostered by a commitment to or influence of assumptions and tenets inherent in the Methodological Reductionistic doctrine.

Inductivism as the only valid scientific method

Acceptance of the Methodological Reductionists' system as a framework for science results in the insistence upon the primacy of the sense-perceptions in the acquisition of knowledge. This subsequently leads to a belief that much of the knowledge accumulated has been the result of pure experience rather than the belief that knowledge is the result of the interaction between observations/experiences and imaginative ideas/expectations. Science textbooks give the impression that the rigour of the empirico-inductive method results in the strengthening of the observation faculties and expanding of reasoning powers (Layton, 1973: 59). Layton states that students come to believe that by rigorously making observations and interpreting data they can act and think like scientists and make discoveries. According to Brush (1976), there is a strong appeal in the idea that any person of moderate intelligence can make a worthwhile contribution to science by diligently collecting and analysing data.

However, such a view is not entirely adequate since the rigour of the Methodological Reductionists' method by itself is insufficient for the construction of theories. In the opinion of Cavendish Professor of Physics, Professor Brian Pippard (1972), one needs more than a rigid methodology; one has to learn to apply intuition and imagination. Moreover, major discoveries in science reveal that much more is involved than just observations and analyses in the formulation of new ideas. They show us that bold imaginative leaps are made in the dark, to be later confirmed by observations and experiments. Consider, for example, the benzene ring of organic chemistry, postulated by Kekulé (Taylor, 1966: 25). His original conception that molecules of aromatic substances are formed of chains of atoms coiled in a ring, came to him in a half-waking dream. His hypothesis had to wait until the physicists' methods of wave-mechanical calculation were used to establish the theoretical stability of the ring structure. This example illustrates that it is not the inductive approach that leads to scientific discoveries. Intuition, imagination, creativity, and other personal characteristics together with observations and experimentations are necessary for bold conjectures and new ideas.

School science's emphasis on the process skills (observation, analysis, discrimination, etc.) and on the rote learning of disembodied scientific facts means that science teaching pays scant attention to the development and consolidation of creative skills and to the role of intuition and imagination in all that which constitute science. This study, however, still maintains that rote learning of scientific facts has a place in science education but it should not be regarded as the sole source of knowledge. The current approach is such that it inhibits creativity and students gradually come to accept and expect a didactic method of teaching. They then find it difficult to participate in discussions, tutorials and seminars. They become conditioned to being passive recipients of packaged knowledge.

Historical interpretation of science

Kuhn (1970a) claims that science textbooks mainly provide an interpretation of the history of science which reflects the influence of the positivistic rationale. He argues that science textbooks present misconstrued ideas of how discoveries in science have been made. The following examples show how textbooks give a distorted view of the historical context in which a particular achievement occurred. The BSCS, Green Version (1963) - a popular textbook for secondary students - describes the origin of Gregor Mendel's theory of genetics, proposed in 1865, in the following manner:

> First, instead of studying only the relatively small number of offspring obtainable from a single mating Mendel used many individual matings [of plants]. He then pooled the results of these matings .... Second, by working with large numbers of offspring, he was able to apply mathematics to the results .... He was able to analyse his data and discover definite ratios of characteristics among offspring. Then by using algebra, he was able to show a pattern in heredity that could account for these ratios. In other words he developed a theory to explain his data (p.535).

This interpretation of the manner in which Mendel discovered the genetic theory clearly reveals the influence of the empirico-inductive method - accumulating data and then formulating theories. If one subscribes to the view that all observations are theory-laden and that interpretation of data is meaningless without prior expectations, then it becomes difficult to agree with the textbook's explanation of the procedure used by Mendel. It is difficult to believe that Mendel could have collected the data first and developed the theory afterwards. The setting up of the study, the nature of data to be collected and how they are to be analysed require a prior hypothesis; for without some prior idea, it is difficult to organize an experiment. Furthermore, the simple ratios of three to one as reported in his data is too good to be true - the inevitable statistical fluctuations that are so much a part of biological experiments dealing with dynamic, heterogeneous systems are missing. It is more likely that a researcher would first develop a theory or hypothesis with its mathematical relationship and then attempt to adjust the experimental results within the parameter defined by the theory. Dunn (1965) and Waerden (1968) state that Mendel formulated the theory and somehow selected data that agreed with his theoretical prediction, discarding the fluctuations. Fisher (1973) rejects an inductive interpretation of Mendel's discovery. He speculates that it is possible that although Mendel might not be guilty of adjusting the experimental data, his workers may well have been involved in deliberate rearranging of results. Fisher comments that "there can be no doubt that the data from ... [Mendel's] experiment have biased strongly in the direction of agreement with expectation [or preconceived theory] .... It remains a possibility among others that Mendel was deceived by some of his assistants who knew too well what was expected. This possibility is supported by independent evidence that the data or most, if not all, of the experiments have been falsified so as to agree closely with Mendel's expectations" (p.531).

This study takes the stand that science textbooks err when they depict the development in science according to the Methodological Reductionistic doctrine. Here is another example of a textbook's interpretation of a scientific discovery - an interpretation that appears to reflect a profound influence of the Methodological Reductionists' explanation of science methodology. The CHEM Study chemistry text states that a scientific discovery is believed to be "built upon the results of experiments" (1963:2). This statement is reinforced when the text attempts to recount how Dalton discovered the atomic theory.

> In the first decade of the 19th century, an English scientist named John Dalton wondered why chemical compounds display such simple weight relations. He proposed that perhaps each element consists of discrete particles. Suddenly many facts of chemistry became understandable in terms of this proposal (p.236).

In this textbook description, it is implied that Dalton first found by experiment that simple numerical ratios such as two to one, occur in the weight of elements in different chemical compounds. Afterwards the atomic theory was developed to explain this fact. Several studies show that this account does not adequately depict the manner in which Dalton is reputed to have arrived at his ideas about atoms. Nash (1956) found that the chemical reactions performed by Dalton did not actually yield whole number ratios. Experimental results concerning atomic reactions are very often approximations of the theoretical yield. It is almost impossible to derive results without any experimental error. Nash concludes that Dalton must have developed his theory and then 'corrected' his data to agree with the theory. In addition, Smolicz (1970: 116) has indicated that Dalton himself denies formulating his hypothesis on the structure of matter merely on the basis of his empirical investigations. He (Dalton) stresses his debt to Newton for having introduced him to the heritage of philosophical atomism which helped him in formulating the atomic theory.

It can be concluded that if one is guided by certain assumptions and beliefs according to the traditions of the Methodological Reductionists then it is possible to sustain misleading ideas about scientific discoveries.

The cumulative nature of science

One conception of science commonly found in science textbooks is that the growth of science is cumulative. For example, Grogan (1970:13) states that "science progresses by the accumulation of facts derived from observation and experiment". The New Zealand 6th Form Biology Manual (Department of Education, 1970: vii) mentions that science is perceived as a "progressive activity with each generation building on the accumulated knowledge of the past". The PSSC text (1965) describes physics as being like a great building under construction. Some parts are finished, some are not completed and some are yet unstarted. It is stated that "the great foundations of physics are well laid ... these remain unchanged ..." (p.3). Such expositions give the notion that progress in science is cumulative and that certain parts are well established against further change. The position at issue has been given a clear formulation by Stent (1969: 111-2):

> /T/here are *some* scientific disciplines which, by reason of the phenomena to which they purport to address themselves, are *bounded* ...., /G/enetics is not only bounded, but its goal of understanding the mechanism of transmission of hereditary information *has*, in fact, been all but reached. Indeed, ... even such much more broadly conceived scientific taxa as chemistry and biology are also bounded .... The goal of chemistry of understanding the principles governing the behaviour of chemical molecules is ... clearly limited. As far as biology is concerned ... there now seem to remain only three deep problems yet to be solved: the origin of life, the mechanism of cellular differentiation, and the functional basis of the higher nervous system .... /T/here is immanent in the evolution of a bounded scientific discipline a point of diminishing returns; after the great insights have been made and brought the discipline close to its goal, further efforts are necessarily of every-decreasing significance.

This explanation views scientific progress as a whole basis of one particular sort of progress, namely the step by step filling in of a crossword puzzle. We have here an accretional or cumulative view of the progress of science, subject to the idea that each successive accretion inevitably makes a relatively smaller contribution to what has already come to hand.

But how did this interpretation about the growth of science come about and what is wrong with it? Kuhn(1970a) states that textbooks' interpretation of the development and growth of science is due to the acceptance of the positivistic (Methodological Reductionistic) epistemology. The positivists, according to Ackerman (1976), believe that science grows by the accumulation of simple observation sentences which have been found to be true. The principle of verification is central to the acceptance of the cumulative view of science. According to Ayer (1976) and Carnap (1959), the principle of verification is supposed to furnish a criterion by which it can be determined whether a sentence is literally meaningful. It is said that a sentence is meaningful if and only if it is analytic or it is synthetic. The truth of a synthetic sentence may be verified in the following sense: if a finite number of simple observation sentences are all validated to be true by observation then the scientific statement must be true as it is regarded to be a logical consequence of these true observation sentences. Such an approach is seen to build up scientific knowledge on the basis of accumulating verified simple observation sentences. The positivists' emphasis on the verification of scientific sentences leaves them no room for refuting such sentences, once their truth has been established. Therefore, new and better theories are not regarded as overthrowing old theories but merely subsuming them and thereby providing an extended meaning to each observation sentence. Successive bodies of knowledge can be compared because observation terms are not incommensurable. If the growth of science is to be interpreted according to the positivistic argument then the progress in science could be seen as being cumulative. There is another possible reason for the view of scientific progress as being the sequential filling-in in greater and greater detail of pieces of information. This is the outcome when one only accepts the puzzle-solving activities of normal science without regard to revolutionary science (Kuhn, 1962). Progress of normal science involves accumulation of new, factual and observational knowledge together with improvement in measurements, more sophisticated techniques of analysis, etc. (Stenhouse, 1979). Textbooks lend support to the cumulative view of progress in science by referring "only to that part of the work of past scientists that can easily beviewed as contributions to the statement and solution of texts' paradigm problems" (Kuhn, 1970a: 138). Partly by selection and partly by distortion, textbooks represent science as developing and stockpiling linearly towards the progress of science. Since the aim of science textbooks is pedagogic efficiency, the books rewrite the past in a manner that the student does not master all the 'wrong' ideas of the past. But the general effect is acceptance of the idea that science progresses by the process of accumulation.

The second part of the question was: What is wrong with the cumulative view? Here we have two issues to consider:

(i) the adequacy of the Methodological Reductionists' tradition; and

(ii) the role of normal science.

Magee (1975) maintains that the inductive method does not advance knowledge; it simply reinforces our belief in our theories. For example, centuries of observation had only helped to 'confirm' the theory that the world was flat. Scientific knowledge of the world did not advance until the theory had been falsified. Furthermore, if science is perceived chiefly as a puzzle-solving activity of normal science, in which research workers try both to extend successful techniques, and to remove problems that exist in some established body of knowledge, then the progress in science will be seen mainly as being additive. However, science does not consist of just normal science. There are periods when crises occur and the old discipline or the existing paradigm is increasingly unable to solve pressing anomalies. Kuhn (1970a) considers paradigms as something "global" from which rules, theories and the like can be abstracted, but to which no statement of rules, theories, and so forth can do justice. A paradigm consists of a "strong network of commitments - conceptual, theoretical, instrumental, and methodological" (p.42). A paradigm includes "some implicit body of interwined theoretical and methodological belief that permits selection, evaluation, and criticism" (pp.16-17). Many scientists spend their life working within normal science, extending and working out the problems within the current paradigms.

There are times when the current paradigms of normal science are challenged, threatened, and overthrown completely by a new paradigm. This is what Kuhn (1970a) calls "revolutionary" science. When a scientific revolution takes place, old and new paradigm components are unable to communicate across the gap; theoretical terms no longer possess the same meanings; they take on meanings of the paradigms with which they are associated. The adoption of a new paradigm marks a complete break with what was earlier thought of as science; under the new paradigm science no longer has the same purposes or the same standards. What formerly counted as science is no longer science. As Toulmin (1972a) has put it, "a scientific revolution involves a complete change of intellectual clothes" (p.101) or, according to Rescher (1978: 48), "a fundamental change of mind". For example, the overthrow of the phlogiston theory and the change from Ptolemaic to Copernican astronomy are cases of changes in scientific knowledge in which the older theories have not been subsumed under the new theories but rejected. The medicine of Pasteur and Lister does not add to that of Galen or of Paracelsus, but replaces them. Relativity brushes aside questions regarding "the fine structure of the electromagnetic aether. Descartes' vortex theory explained why planets moved in the same direction, a fact for which the physics of Newton's Principia had no explanation, and so on" (Rescher, 1978: 48). Science is, therefore, not strictly cumulative because paradigms determine what kinds of questions and answers are in order. With a new paradigm old answers may cease to be important. With the acceptance of a new theory, there are new problems to solve and old problems and ideas to be rejected. While normal science is additive, revolutionary science is "transformative" (Stenhouse, 1971) or "subtractive" (Rescher, 1978). Today's major discoveries represent an overthrow of yesterday's - the big findings of science inevitably contradict its earlier findings. Science is, therefore, a matter of constantly rebuilding from the very foundations and not the successive building on the accumulated knowledge of the past. What Kuhn, Toulmin, Rescher and others are saying about the progress in science do not support many science textbooks' interpretation of the progress in science.

'Objectivity' in science

A lot has been written supporting or justifying 'objectivity' in science and 'objectivity' as a variable representing scientific attitude; at the same time there has been a great deal of criticism directed at the influence of scientific 'objectivity' on the social sciences and charges have been made that science is 'objective' in the sense that it is cold, impersonal and amoral. Before the cogency of these statements and charges can be evaluated it must be seen if it is possible to clear some of the appropriate meanings of this key term. It seems that because of a systematic ambiguity in the use of the term 'objective', it is difficult to assess claims for and against the status of objectivity. If by 'objectivity' one means the study of external, observable, physical phenomena of pure science (although not all entities studied under pure science are external, observable and physical) - the things of the world - as opposed to the study of the individual and the society in the behavioural social sciences, then it is, in this narrow sense, adequate (but not complete) to say that the pure sciences deal largely with the study of objects and physical phenomena. 'Objectivity' used in this particular sense is unproblematic. However, when its usage in relation to sense-perceptions as source of knowledge, the truth of statements, the reliability of scientific methodologies and the observer (the researcher, the scientist, etc.), is not specifically stated then confusion results. Rudner (1966: 77-83) contends that there is a systematic ambiguity in the use of the term 'objectivity'. According to him, the ambiguity stems from being unclear about those uses of 'subjective' and 'objective' that mean something very much like 'psychological' and 'nonpsychological' respectively, and those uses of 'subjective' and 'objective' that mean something like 'biased' (or 'error-laden') and 'unbiased' (or 'error-free') respectively. These are two different pairs of meaning.

If the term 'objective' is to mean 'unbiased' then, according to Rudner (1966), it can be used to apply to four different things: (1) "the verisimilitude of ideas, i.e., the replicalike character of mental imagery, (2) the truth of statements, (3) the reliability of methodologies, and (4) the psychological dispositions of an investigator to have, or believe, or employ the kinds of ideas, statements, or methodologies mentioned under 1, 2 or 3." Since the last point is derived from points 1,2 and 3 and since it is crucial to the discussion of those points, it would be more fruitful to consider point 4 in conjunction with ideas, statements and methodologies rather than independently.

1. The view that objectivity is to be found in a certain correspondence between our ideas and those things of which they are ideas is often attributed to John Locke. Many people hold that our mental "picturizations" are objective in so far as they exactly resemble what they are "pictures" of. This is a sort of "snapshot theory of objectivity". The difficulty with this notion of objectivity is that the sense of "exact resemblance" that it involves is quite obscure. Another point is, not all ideas of entities are picturizations i.e., not all entities can be construed as pictorial in character and thus there is no way of establishing the existence of exact resemblances. The view that impressions, ideas, theories, and even all scientific knowledge is objective presupposes that there is absolute knowledge, and in some mysterious way we can directly compare our ideas of this knowledge with the absolute knowledge. If there is absolute knowledge devoid of human awareness then we have no access to such knowledge. All knowledge is subjective i.e., it is a consequence of the interaction of ideas, events, phenomena, etc. with the observer. Each piece of knowledge has its subjective element. Therefore, it is difficult to talk about 'objective' knowledge in this sense.

2. The usage of objective in the sense of 'true' refers, in general, to the semantic conception of truth. This implies that 'true' or 'false' are construed as predicates that apply to sentences or statements. To identify objectivity with truth is to make 'objectivity' a predicate of statements. This is a well-trenched usage, for example, when we speak of someone as giving "a factual, or objective, account" of something, we appear to be saying little more than it is a true account. This view of the nature of objectivity, according to Rudner (1966), seems relatively unproblematical.

3. There is another well-trenched usage to which the term 'objectivity' is put. Consider "he adopted an

objective mode of investigating the facts" or "he employed an objective method in investigating..." etc.. Here, it seems that the application of the term is, to *means* or *methods* of conducting inquiries. One meaning of this usage is that the scientific method is more *reliable* and the sense of 'reliability' can be satisfied by making the observation that it is less liable to *error*. To say that a method is 'absolutely reliable' is to mean that error is impossible. If 'absolutely reliable' is equated with 'absolutely objective' then the scientific method can only be non-objective. Empirical enquiry is logically not the kind of inquiry that can be undertaken in a manner to make error impossible. Also consider that formulation of hypotheses, design of experiments, use of measuring instruments, collection of data, analysis of data, comparison of data with hypotheses, etc. all require human input and subjective interpretation and therefore an 'objective' ('unbiased', 'error-free' and 'absolutely reliable') method of scientific inquiry does not exist. So to speak of an objective method of science is meaningless.

We have another tradition of 'objective': the picture of the objective scientist (an issue that was considered earlier in Chapter 2). 'Objective' in this context means detached, dispassionate, emotionally neutral: like a word processor where the input is automatically displayed on the screen. The objectivity attitude can be traced back to the Baconian tradition. He had fostered the idea of the "disinterested observation of nature" (Goran, 1974: 62). According to Nisbet (1974: 18), Bacon had incessantly sought to engage our attention to the notion of an 'objective' practitioner of science.

The above are some of the usages of the term 'objective'. What follows now is an exposition of these usages of 'objective' in science and science education and reasons why criticisms concerning objectivity are so commonly made.

According to Cawthron & Rowell (1978: 32), science textbooks are often preoccupied with the existence of "objective reality". Reality is accepted as given, existing apart from human agents (in the sense of absolute knowledge) and it is assumed that such agents (in the sense of objective practitioners of science) can approach a comprehension and appreciation of reality by applying the process of perception. The process of perception although involving human agents is itself depersonalised (true to the traditions of Bacon and Locke), as the actual socio-psychological and individualistic aspects of any particular act are assumed to be of little significance in the acquisition of scientific knowledge. Not only is it regarded as of little significance but the learner (scientist, observer, researcher, etc.) is required to expunge all personal expectations, biases, etc. during the process of perceiving an event or a phenomenon. This picture of how knowledge is acquired and the role of the learner inevitably result in the portrayal of science and the scientist as cold and impersonal. The depersonalisation of science and the scientist is believed to be a contributory factor in the drift from science to arts (Kaiser, 1969; Bondi, 1975; Matthews, 1975). A similar conclusion has been arrived at by Nay & Crocker (1970) and Glass (1971) who point out that far too much attention has been given to the factual knowledge but little recognition of the influence of personal attributes of the scientist and the socio-psychological aspects towards the growth of science.

It is being suggested that one of the possible reasons for the predominance of the cold and impersonal image of science and scientists is the profound influence of the Mathodological Reductionist methodology of science. The Methodological Reductionist or the empirico-inductive view excludes all subjective and socio-humanistic influence on the methods of investigating in science.

The traditional methodology is excessively formalistic and overly mechanistic. Methodological Reductionism stresses that objectivity is ensured by the conceptual neutrality of observation statements or propositions. These are supposed to be based on observations or sense-perceptions and are thus regarded as free from unfounded speculation and the constraints of observer effects. According to Methodological Reductionist tradition the observer is 'objective' in the sense that he/she is emotionally neutral, dispassionate and detached.

The consequence of the influence of the Methodological Reductionist theory of science is that school science tends to project an idealised and misleading picture of the scientist. The scientist is made out to be existing apart from the knowledge created. The picture one gets is that there is absolute knowledge and the learner, as a passive recipient, is able to capture an 'exact resemblance' of this absolute knowledge. The Methodological Reductionist tradition overlooks the interaction between sense-observations and the observer's expectations, beliefs, moods, etc.. Although 'objectivity' (more like rationality) is of undoubted value and usefulness in the development of scientific knowledge, excessive demands for 'objectivity' (in the sense of absolute knowledge and emotional neutrality of the observer) very often results in the dehumanisation of the 'scientific process'. For, in the attempt to achieve this objectivity the observer is forced to expunge any emotional influence and personal expectations from his observations.

The Methodological Reductionists' support for 'objectivity' in science is invalidated by the observer effects. The observer effects shade or taint the observations. The expectations of the observer change not merely the observation of the experimental results but the results themselves. For example (Judson, 1980: 171), a routine but important measurement in medicine is the blood count. For many years, textbooks have told us that if the technique was followed correctly, two or more samples from the same blood should not vary in cell count beyond narrow limits. And in practice, laboratory technicians regularly reported counts that kept within the limits. But when the actual procedure was checked by a more accurate technique,discrepancies were found to be greater than the supposed limits. In other words, many observers for many years were making and recording observations that agreed with their expectations, but not with the supposedly 'objective' realities. According to Polanyi (1958), the scientist never ceases to be a human being with human passions and weaknesses. He can in no way avoid what Polanyi calls the "passionate, personal human appraisals of theories" (p.15). There is a difference between the scientist's involvement in scientific research and the required student involvement in experimental work. The scientist, in his professional activity is guided by and finds his incentive in his beliefs, expectations and pet theories, although he is required to suppress these when communicating his findings through scientific journals. Scientific papers "in the form in which they are communicated to learned journals are notorious for mispresenting the processes of thought that lead to whatever discoveries they describe" (Medawar, 1969: 8). However, the school student does not have the same liberty. Objectivity is imposed upon him through (a) textbook exposition of the procedures for doing science and descriptions of scientists' own works and (b) teacher emphasis upon the virtues of objectivity.

The Methodological Reductionistic-influenced science teaching implies that the concept of objectivity is context-free or independent of any paradigm. For Walsh (1977), the concept of objectivity is not context-free. He maintains that objectivity is a concept "grounded in the context of a conventionally understood and institutionalised body of public practices, that is, the scientific paradigm" (p.42). In other words, the scientific community, through its dominant and all influential paradigm, has laid down rules of the manner in which the scientist should investigate and talk about natural phenomena. These formulations are then labelled 'objective'. But when school science emphasises objectivity it is conveyed as context-free scientific norm. Consequently a stereotype of science has been established that has little likeness to the descriptive accounts of the functioning of science reconstituted from an examination of historical evidence.

The implications of the 'objectivity'(i.e., absolute knowledge and dispassionate researcher) image extend beyond just school science. The success of science is seen as validating the usefulness of such scientific attributes as objectivity. Scientists are perceived as cultivating objective consciousness and such a quality is perceived as a true, real and dependable way of unearthing the secrets of nature. Because the success of science is seen as a consequence of the objectivity ideal, there is the tendency to utilise this ideal in other fields in the hope of bringing about similar successes. According to Roszak (1969), objectivity has become the commanding life style of modern society - the one most authoritative way of regarding the self, others, and the whole of each individual's enveloping reality. Unfortunately objectivity contributes to alienation. When social problems and issues involving humans are treated on the sole criterion of objectivity, something of the human compassion is lost. The resulting indifference and callousness encourages anti-scientific attitude and a trend towards an increasing criticism of science. While the implications of objectivity in terms of its effects upon the society in general are deleterious, the immediate concern for school science is equally important. Objectivity as a dominant image of science deters the student from developing and maintaining an appreciation for science subjects.

Review of chapter

The restructuring of science curricula has been based primarily on educational ideas without recourse to any theoretical justification from the modern philosophies of science. This oversight has resulted in the utilisation of inadequate teaching and learning processes and has also given rise to several misconceptions about science. Science education emphasises observation and other basic process skills as fundamental for the acquisition of scientific knowledge. It thereby fails to give due consideration to the role of personal beliefs, imaginations, and intuition in not only the selection of the relevant data but also in the generation of new ideas. For pedagogic convenience, science education offers the student a rigid scientific methodology that fosters a constricted view of science and so discourages divergent thinking and stultifies creativity.

It appears that school science has been influenced by certain tenets of Methodological Reductionism. Implications of commitment to the traditional view of science have been detected in school science. The school science's incorporation of such views of science as: that inductivism is the only valid method of scientific activity, that the growth of science is cumulative, that discoveries in science has been due mainly to the practice based on inductive empiricism, and that science is objective provides sufficient grounds for believing that there is a large degree of consensus between school science and certain traditional philosophies of science. But because the original formulations of the traditional doctrine, in the spirit of its historical predecessors such as Bacon, Locke/Hume, Mach, and the Logical Positivists have been found to have several weaknesses, the same is equally true of the ideas inherent in school science. Therefore, science education continues to contribute to the misunderstandings about the nature of science and scientific practice.

In the next Chapter, I shall examine a number of additional beliefs/images of science inherent in school science and point out reasons why these are not only inadequate but also misleading.

CHAPTER FOUR

CONCEPTS OF SCIENCE AND OF THE WORLD

As mentioned earlier, any science curriculum along with its translations into practice embodies particular images of the nature of man as scientist, of scientific knowledge, and of the relationships between them. These images are often made explicit but they can sometimes only be inferred from information provided in textbooks, curriculum statements, and so on. At other times, they are a result of neglect by science education to refute or even discuss the pictures portrayed in popular literature and elsewhere. The line of argument taken in this chapter is that the images of science encountered by students are in part a consequence of the influence of certain traditions within science education and within the 'philosophies of science'. By 'philosophies of science' I mean any/all belief systems about science, including assumptions that are not consciously held. This may appear to be too inclusive, a 'blanket answer'. However, I recognise the problem, but I intend to examine some of the specific possibilities within the total spectrum of 'philosophies of science'.

The beliefs we accept and utilise are often held unconsciously, and are rarely reflected upon. Moreover, when reflection does occur, it tends merely to depict these beliefs/images as natural representations of 'how things are'. We often have a taken-for-granted view of the world and think with our beliefs rather than about them. However some of these beliefs/images about science inherent in school science will be shown to be inadequate and misleading, both for the continued progress of humanity and for a better appreciation of science. I will attempt to show that school science embodies the following images/beliefs and these are a legacy of specific traditions within the total spectrum of 'philosophies of science':

1. that science is neutral;
2. that science is infallible, certain and true;
3. that science is overly materialistic;
4. that the central role of science is to facilitate man's domination over nature;
5. that science will provide all the answers to social and environmental problems - the fallacy of scientism; and
6. that all scientific phenomena can be explained if they are reduced to the laws of physics (that is, reductionism).

I shall argue that such imaginations about science are based upon misconceived ideas which have rarely been reflected upon and seldom examined.

Is science neutral?

Education is seen, to a large extent, as being a paradigmatic indoctrination of the traditional view of science (Cawthron & Rowell, 1978; Passmore, 1978), resulting in the propagation of certain images/beliefs about science. For example, science is perceived to be neutral and supposedly uninfluenced by ideological and social forces. Protagonists of the idea of neutrality, such as Chain (1970), maintain that "the activities of science are morally and socially value-free. Science is the pursuit of natural laws, laws which are valid irrespective of nation, race, politics, religion or class position of their discoverer .... The uses to which society may put science may be good or evil, [but] the scientist carries no social responsibility for those uses, same as normal citizen" (p.166). This type of argument is commonly made to support one's belief in the neutrality of science. While it may be true that natural laws are valid irrespective of nation, creed, etc., the formulation of such laws is very much a part of

human activity. Personal expectations, social forces, and economic and technological conditions are some of the factors that play a crucial role in the development of scientific ideas. It has been found that science is embedded in culture and social values. According to Bronowski (1969), social and economic forces have an influence on the directions that science follows. The progress in science is often determined or initiated by existence of social and economic problems and by the ingenuity and intuition of individual scientists. Scientists, like other human beings, are affected and conditioned by their social backgrounds; it is difficult to perceive that they operate in a social vacuum, which of course they do not. Science injects new ideas into the familiar culture and culture influences science (Bronowski, 1969). No scientific development can be regarded as being external to the scientist and the society in which he or she exists.
For example, Hessen (1931) a Russian physicist, explored in some detail the practical, technical, and economic problems that Newton's work Principia was trying to solve at a theoretical level. There was a need for more efficient road and water transport, better pumping and extraction equipment were required for mining, and an improved understanding of the flight of balls and bullets - ballistics - was sought. Hessen went on to show the problems in physics that these requirements gave rise to and how the framework of Principia was established by a consideration of these problems.

The traditional assumption that the scientist carries no social responsibility for the various uses to which scientific theories are put, is no longer justified. Society expects and the scientist now accepts that he is accountable for the ways in which his discovery is put to use. In the face of increasing criticism from the public in general, scientists and other experts have formed societies to monitor research activities in certain fields of science. For instance, in the early

1970s, members including molecular biologists, of the U.S. Science for the People group, got together to call for a temporary halt to genetic engineering research. They pointed out that the hazards associated with the creation of new, never-before-seen strains of bacteria and virus far outweighed the possible benefits. The campaign was picked up in Britain by the British Society for Social Responsibility in Science (BSSRS). Through their actions, the British government set up the Genetic Manipulation Advisory Group to regulate activities in genetic engineering (Albury & Schwartz, 1982: 55-56). Such groups as BSSRS, Science for the People, and the Society for the Social Responsibility of Scientists (SSRS) in the U.S., would not be active if they did not perceive their social responsibilities. There is now increasing agreement that scientists have a responsibility to answer for what they do in research and the way they do it: a moral and ethical responsibility (Williams, 1983).

Rose & Rose (1971) point out that emergence of big science destroyed the myth of neutrality. Massive financial input by state and industrial enterprises are now vital for research in general and high energy physics, genetic engineering, etc.. The exponential increase in dependence upon outside financial help means that the direction, scope, and nature of scientific researches are to some degree dictated by external priorities. Governmental and industrial research contracts in universities reveal external intervention in research activities (see Price, 1963; Nelkin & Rip, 1979). The involvement of physicists in the Manhattan Project for the development of the atomic bomb and the well known Lysenko affair concerning genetic research in the USSR demonstrate the interaction of science with political ideology. It can therefore be argued that science done with a particular society reflects the norms and beliefs of that social order. Science thus ceases to be value-free and neutral but instead becomes a part of an interacting system in which internalised ideological assumptions help to determine the very experimental designs and theories of scientists themselves. It is questionable whether science would have developed in the manner it did if the social, political, and economic problems and pressures were otherwise. Some writers, for example, Farago (1976: 69), maintain that classical science could be regarded as a neutral activity. However, this claim is doubtful considering the findings of Hessen and furthermore, recent interpretations from the history of science reveal that science did not proceed in a social vacuum (see Basalla, 1968; Kohlstedt, 1976; Macleod, 1977). Interests and attitudes of practising scientists are inextricably mixed with those in authority. Shifts in social and ideational balance have affected attitudes towards science.

In a paper presented at the ANZAAS meeting in Auckland, Penny Fenwick (1979) exposed science's condonation of state's authority, capitalist (not forgetting the socialist) economy and social relationships in support of her argument calling for a concentrated rejection of supposedly value-free or neutral science. The myth of neutrality and the awed reverence with which the public regard science has meant that public participation in the conduct and application of scientific research has been kept to a minimum. In turn, scientists have tended to be sympathetic towards the myth of neutrality because such a myth about science, according to Ezrahi (1971) and Ronayne (1976), helps the scientific community avoid having their work subordinated to standards extrinsic to science and also helps to protect scientists from external public interference. This view is further supported by Johnston's (1976) observation that scientists have been unwilling to accept that the knowledge they produce may be determined by its social context, because such an admission could threaten their claim to scientific neutrality. This could then lead to external demands for a greater say in the activities of the scientist. Such a stand by scientists is no longer viable because of the growing bureaucratization of science (Goodlad, 1973).

One of the possible reasons for the existence of the view that science is neutral can be traced to certain tenets of Methodological Reductionism. The Methodological Reductionistic concern with the inductive method, with the scientist as the neutral observer, and with empiricism has given rise to a conception of science in which personal characteristics and expectations of the scientist and the social and political influences have been largely discarded. As a consequence, it became totally acceptable to maintain that science is neutral. To accept that external factors influence the growth of scientific knowledge is to concede that there are no 'detached' observers and no pure observational language. For the Methodological Reductionists this would be self-destructive because the basis of scientific theories is the idea of pure observations from sense-experience. Meaningful propositions are only capable of being verified by sense-experience if the sense-experience has not been subjected to any personal beliefs and prejudices. Johnston (1976) points out that if one attempts to account for the content of scientific knowledge by social causation then one faces the positivistic argument. The argument is that social causation is irrelevant to the understanding and development of scientific knowledge because such knowledge is supposedly the result of the interpretation of objective reality devoid of human implications.

School science inadvertently supports the neutrality myth by portraying the scientist as being objective, rational and neutral, uninfluenced by external factors. In addition, many science teachers consider the teaching of science as a method of academic excellence. Such teachers, usually classified as "theorists" (Jenkins, 1981) demand rigour, academic excellence, and a high level of knowledge in science teaching. The theorist is mainly concerned with the teaching and learning of scientific facts, principles, concepts, and experimental procedures. He or she is not concerned with the extensive interaction of science and society. As a result of this neglect, students come to believe that science is neutral and value-free. Science textbooks are often equally at fault. With their emphasis on science processes and the structure of the various bodies of knowledge, they have tended to overlook how knowledge has been created and how scientific theories and facts embody the dominant ideas of the society. The various applications of scientific knowledge, the social background and personal characteristics of the scientist, the social situation at the time that provided the impetus for the formulation of a particular scientific theory, etc. are often treated as footnotes or completely neglected. Some critics of scientific neutrality, such as Levy-Léblond (1976) and Rose & Rose (1976), see deeper implications in this myth. Besides claiming that school science is quite mutilated, Levy-Léblond maintains that science education deprives the student of the significance of the role of dominant belief systems in science by preserving the image of neutrality. For Levy-Léblond, the teaching of science ceases to be an activity with any social or moral implications and results in the isolation of the activities within the classroom from the 'real world' outside.

The myth of infallibility, truth, and certainty

The view of science as infallible, true, and certain has its origin in the nature of modern science propounded by advocates of induction and empiricism. Positivists, such as Mach (1960) and Schlick (as cited by Ayer, 1976), accept conclusive verification as the criterion for establishing the truth of any meaningful proposition.

The truth of any scientific statement is therefore assured by verification through sense-experience. The implications are that scientific knowledge so derived are true and certain. The myth of certainty and truth are further supported by the inductive method of science. Induction in logic means arguing from particular facts, regarded as true and certain, to general principles or laws. The conclusions reached by this kind of inductive procedure would be certain and true (or, to be more precise, as certain and true as the facts from which it starts). This matches with the popular but mythical ideal of science as a body of indubitable knowledge based on established facts from which conclusions are drawn by impeccable logic. The myth persists despite the fact that later-day positivists, such as Carnap (1962), have conceded that the system of induction and conclusive verifiability are totally inadequate for establishing the truth of any scientific statement. Even Ayer (1976: 50) maintains that the truth of scientific propositions "cannot be established with certainty by any finite series of observations".

The myth of certainty and truth is further propagated by popular literature. In popular literature we often encounter statements about science that conjure up images of science as being infallible, certain, and omnipotent. To say of anything that it is scientific, is thought to give it a stamp of truth and certainty. Advertisements owe much of their power to the weight carried by so-called scientific statements; to attribute scientific qualities to some process or other is to stifle criticism. This is the general attitude and advertisers have made considerable use of this attitude. They state the products' effectiveness on the basis of a scientific claim; hence such statements become indisputable and eternally true. Undoubtedly, genuine progress has been made in science but this does not mean that right ('true') conclusions have been reached. Advertisers have misinterpreted the degree of certainty inherent in the scientific method and this misinterpretation has been successfully used as a strong marketing technique. While the advertisers have made effective use of the myth of certainty and truth, this would not have been possible if the public were not so susceptible to such beliefs. This is also an indication that the public has an inadequate understanding of the nature and function of the methods of science.

The notions of certainty and truth in school science

Jevons (1969: 29) and Mackay (1970) have noted that the notions of certainty and truth are firmly entrenched in the minds of pupils. For example, a survey carried out by Horner & Rubba (1978), at a Midwestern American high school, disclosed that 30 percent of the science students believed that scientific research reveals "uncontrovertible, necessary and absolute truth" (p.29) about scientific knowledge. There are possibly many reasons why students subscribe to the idea that science is certain and true. One reason being that science curricula rarely utilise the "narrative of inquiry" approach (Schwab, 1962) which offers a fair treatment of the generally incomplete, tentative and dynamic nature of science. Rather, science as it is taught is often made out to be a collection of incontrovertible facts gathered by unquestionably reliable techniques. Techniques are seldom acknowledged to be inadequate for the solution of major problems (Ravetz, 1978: 276) and if found inadequate they are conveniently left out. Teaching places emphasis upon the conclusions of science, which Schwab calls the "rhetoric of conclusions". Goran (1974: 77) notes that every science has an array of material from established facts to educated guesses. Yet all may be given to the student with equal time and emphasis. In astronomy, the size, shape and motions of the earth are known with more certainty than the distances of galaxies, but both may be taught without attached provisions. All sciences (Goran, 1974) have a tendency to package data and concepts neatly, without loose ends. The results are boxes containing the uncertain as well as certain. This treatment prevents students from realising that what is being taught may represent only the present, tentative conclusions about scientific knowledge. They are not made aware that science is an on-going activity and that no statement can remain (or ever were) absolutely certain. As Popper (1959) pointed out "every scientific statement must remain tentative forever". To be sure, some facts and principles of science have withstood the test of time, but not beyond a certain degree of probability. Scientific principles never arrive at the final truth, but one may hope that they lead nearer to truth, that they advance in verisimilitude, to use Popper's expression. Agnew & Pike's (1982:261) explanation is as follows: certainty rests precariously upon three foundations:

1. observations (the empirical foundation);
2. logic (the rational foundation);
3. faith or bias or values (the nonrational foundation).

Any of these foundations could collapse at any time and thus one cannot consider scientific knowledge as being certain i.e. indubitable, true and uncontrovertible.

When science is presented in an authoritative style, when the majority view of scientific knowledge is empirical, factual and logical, and when textbooks deal mainly with the products of scientific knowledge, then invariably students come to accept that science is certain and true. Another possibility is the consequence of careless simplification of scientific principles, ideas, etc.. According to Nelkin (1977: 148) in the "process of simplification, findings may become explanations, explanations may become axioms and tentative judgements may become definitive conclusions."

Science textbooks through authoritative statements give the impression that what is known and written in the book is true and certain. In Biological Science: Processes and Patterns of Life (1973), laws are stated as unquestionable facts, for example, Liebig's law of the minimum (p.31). No attempt is made to clarify the tentative nature of scientific theories. On reading the text, the initial impression the reader gets is that knowledge is concrete, factual, and validated. The text avoids any mention of anomalies, contradictory issues and uncertainties. In Modern Chemistry (Metcalfe, Williams & Castka, 1974), a popular sixth form chemistry text[1], it is stated that "unlike civil or moral laws which require and restrict, natural laws tells us what does occur in nature" (p.5). Natural laws are accorded an authoritative status in the explanation of natural phenomena. The human agent who is vitally important for the formulation of the law and for the interpretation of nature is left out. One also gets the impression that science is the only legitimate means of explaining the real world. In Modern Physics (Williams, Trinklein & Metcalfe, 1976) limitations of the scientific method are accepted and it is stated that "the validity of a scientific conclusion is always limited by the method of observation, instrumentation, and, to a certain extent, by the person who made it" (p.7). Although it is

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1. Alex Eames (Nov., 1981) visited 56 New Zealand secondary schools during the winter term of 1981 and found that 25 of the 74 chemistry teachers used the text, Modern Chemistry. This together with Modern Physics is the most frequently used textbook in U.S. high schools, according to Weiss (see Yager, 1983).

encouraging to note that the human agent has been allocated a place in the formulation and testing of scientific theories, one still has to be cautious about the unrestrained validating powers accorded to instrumentation and experimentation. Since all scientific theories must have predictive power no set of observations or measurements would be complete in verifying, as true, these theories and therefore, scientific explanations can never be accepted with certainty or be considered as absolutely true. Regardless of the availability of delicate and sophisticated instruments and increased refinement in observation, scientific theories and explanations will continue to retain their conjectural character because this is one of the integral features of scientific knowledge. Even, as Popper (1959) argues, if we hit upon the 'truth' we have no way of knowing that this is the 'truth'.

CBA and CHEM Study each have attempted to teach what chemistry is but both have ignored some issues and overemphasised others. CHEM Study (1963: 11) claims that imprecision is the source of uncertainty and ignores the possibility of inherent lack of certainty in the phenomena being studied. CBA (1964) considers the problem of indeterminancy built into a system in its discussion of electron charge distributions, but does not state the problem accurately. It does not say that it is impossible to specify the location of the electron; rather it says that the task of obtaining "the experimental information necessary to give a valid description of the behaviour of an electron proved impractical" (pp.230-1). In other words, the indeterminancy is not a part of the phenomena itself but a restriction due to limiting powers of experimentation. The PSSC text states, in relation to the uncertainty principle, that the older mechanics and classical physics were naive in thinking we could know the energy, momentum, position and time for the impact of a particle

(PSSC, 1965: 625-6). And the fiction is repeated that somehow we now have a complete explanation of the physical world: "the combined view of wave and particle behaviour (quantum mechanics) covers all we know about nature" (p.639). There are two deficiencies in this type of explanation concerning scientific knowledge. One is that such a description of the growth of scientific knowledge often tends to belittle past achievements and to portray scientists as being somewhat ignorant. However, past scientists were justified in holding a particular view of a certain phenomenon because their understanding and interpretation were dependent upon their prior knowledge, beliefs and expectations. The implication of such an evaluation of classical science is that it conditions teachers to perceive students' own interpretations of scientific phenomena in a similar light. Teachers unwittingly thrust aside students' explanation if it does not correspond to textbook explanation without attempting to find out why students hold a particular view. This attitude destroys students' confidence in their own ability and stultifies independent thinking. Teaching then becomes a dogmatic initiation within a particular paradigm.

The other point is that science textbooks tend to give the impression of a fait accompli through statements such as "the combined view of wave and particle behaviour covers all we know about nature" (PSSC, 1965: 639) or that "the great foundations of physics are well laid... these remain unchanged..." (PSSC, 1965: 3). These types of definitive and authoritative statements give rise to such beliefs as the irrefutability of scientific knowledge; teacher attitude, like in the above situation, and the fait accompli writing styles of some textbooks help to undermine students' confidence in their own ability to provide solutions/explanations, thereby encouraging rote learning of textbook knowledge.

The materialistic image

It appears that much of society's bases of support for science stem from the traditional Baconian ideology that utility and progress, the two virtues of science, will provide humanity with the necessary tools to ever increasing material benefits. Science will inevitably ensure perpetual progress of mankind. Taylor (1978) states that to a large number of people, science is synonymous with material benefits, comforts, and services. However, such perceptions of benefits are also juxtaposed with feelings of concern for universal consequences. Science, in the opinion of Weaver (1966), is also seen "as a sort of mechanical monster, grinding ever forward, producing terrible engines of destruction, forcing everything into dull conformity with inexorable and soulless logic" (p.47). These contradictory views of science one, as a continual source of material benefits and the other as a dangerous force producing inventions that are often perverted to threaten our welfare may both coexist in a single mind. A person may wholeheartedly support cancer research while, at the same time, denounce the peaceful use of nuclear energy. This disturbing double image in contemporary society probably does not have its roots in merely the use of science in socially undesirable ways. Its source may also lie in our conception of science as influenced by certain traditional views of science. According to Biggins (1977), and Brush (1976) the problem lies in our interpretation of the nature and function of science, which has for too long been based upon the Baconian ideology.

The conflicts about the function of science arise from the inadequacy of the traditional framework of modern science to acknowledge the fact that science need not be perceived solely as a perpetual provider of material comforts. The linking of materialism and science has been a consequence of excessive faith in the Baconian method.

It has fostered the notion that by maintaining the primacy of experience and observation, scientific activity can solve any problem. This being so, science has come to be seen largely as an instrument for personal comforts. One cannot deny the fact that improvements in the life of many individuals have been a consequence of scientific and technological advancements but this does not justify an excessive faith in science solely on materialistic basis. The materialistic image, if taken to its extreme, is self-defeating for it raises expectations for material benefits to unattainable levels. Anti-scientific attitude, a decline in confidence and alienation from science eventuate when science fails to relieve man of his problems.

Critics of modern science point out another implication of materialism. They believe that because society has come to expect unlimited material benefits, it is becoming increasingly dependent upon institutions that control and dictate the lifestyle of each individual. Roszak (1972) maintains that scientific development has brought in its train "technological elitism, affluent alienation, environmental despoliation" and specialised institutions.

In terms of science education, the treatment of scientific knowledge within a social vacuum cannot but exacerbate the current conceptions of science. This can eventuate when textbooks raise the expectations of pupils by constantly glorifying the achievements of science while rarely discussing the limitations and failures of science. A more balanced perspective on the function of science and technology is possible provided science education exposes the social role and social consequences of science.

<u>The domination of nature image</u>

A consequence of materialism is that it subsequently leads to a belief that much of the social problems can be resolved if humanity dominates nature and makes it work to its own benefits. The man/nature relationship is commonly interpreted as man against nature or man's mastery over nature. Other than being a consequence of materialism, this belief has its roots in the interpretation of the human evolution. From the time of evolution, human beings were seen as being under the control of nature. Science has been regarded as instrumental in liberating man from the vagaries of nature and gradually helping him subjugate nature.

In addition, the tradition of man against nature, in western thought, also has its source in the Christian doctrine. According to Griffiths (1975), the Judeo-Christian belief supports the separation of man and nature. Man has been given dominion over the fish of the sea and over the birds of the air and over every living thing that moves upon the earth. The Christian doctrine (Tisher, Power & Endean, 1972: 10) puts man further apart from animals, since he alone is afforded a soul. By placing man over the animals, and the spirit outside nature, the Christian doctrine freed the adherents from the fear that nature could exact retribution over them for any attempt made to dominate her (Easlea, 1974: 79). Accordingly, man has elevated himself above the rest of creation and therefore perceives himself as master or manipulator of nature. This anthropocentric view has been put to the forefront by Lord Bacon. One of Bacon's aspirations (Passmore, 1978: 25) was that human beings should use their scientific knowledge in order to extend their dominion over nature. The aim was not only to promulgate the methodology that he believed would gain for man his domination over nature but also help to legitimate that programme of domination for the "relief of man's estate" (Leiss, 1972). In Leibnitz (Glacken, 1971) the philosophy is even more explicit. He saw man's mastery over nature as the basis for ameliorating the lot of mankind and the idea of progress was linked with the idea of control over nature.

Science thus strives for the subjugation of nature by man, but in doing so it gives rise to problems which it presently is incapable of resolving. The constant appeal to science for greater technological commodities through the subjugation and extensive exploitation of nature has resulted in the emergence of several major problems. Diminishing natural resources, environmental pollution, the stress and illnesses of twentieth century life-style, etc. are the kinds of problems confronting society. Furthermore, the concept of man's dominion over nature, according to Habermas (1971), Roszak (1972) and Easlea (1973), has given rise to the practice of man's domination over man. There is a possibility that institutionalisation of specialised knowledge and specialised activities as a mechanism for social control can be perceived as being an extension of our belief in man's dominion over nature.

This study maintains that the anthropocentric view is inadequate in today's conceptualisation of science. Its presence can only aggravate misunderstandings about the function of science. The anthropocentric view is also narrow and restrictive. To say of the earth as being designed for the sake of life is one thing; to say that it is made for man alone and to use as he sees fit is another. The current crises in science and some of the problems associated with scientific and technological developments are, to some extent, a consequence of man's attempt to subjugate nature rather than to seek and maintain a more harmonious relationship. To stem the disillusionment with science and technology and to check the drift from the science to the arts may require a suspension of certain of the traditional philosophical/ methodological bases of science and an examination of current thinking on the nature of science.

Scientism

According to Jacobsen (1972), scientism is a distorted view which portrays science as the ultimate human endeavour, capable of solving any problem. The public, including students and some scientists, possess an uncritical faith in the power of science (Henle, 1966; Eastman, 1969; also refer to Cameron & Edge, 1979) thereby exhibiting a scientistic tendency. The scientistic belief appears to be a manifestation of the Methodological Reductionistic explanation of the source of knowledge. This philosophy, by overemphasising the validity of sense-experiences and empirical investigation, has generated the belief that all knowledge should be brought within the sphere of the empirical. It has also reinforced the sentiment that science should be the only authority of belief or the only criterion of action. By extending the claims of empirical investigation it denies that there can be any genuine knowledge outside its scope (see Macquarrie, 1982: 60). The empirical method, as practised in the natural sciences, has proved to be successful, and can be usefully extended to some aspects of human life, but what is most distinctly human, freedom, emotions, etc. cannot be brought into the empiricist net. The very success of the empirical method in the natural sciences has led to its application in other areas of human activity. Marcuse (1968) and Habermas (1971) point out the threat of scientisation of politics. Decisions which are essentially social or political in nature are presented to the public as technical or scientific decisions. The justification is then based upon appeal to the supposedly neutral and objective character of the empirical method. The public, in turn, are deprived of challenging decisions formulated on the basis of scientific 'rationality' (a scientific norm already explored in Chapter 2) because this is regarded as safeguarding the 'objectivity' (in the sense of being 'unbiased' or 'error-free') of the exercise carried out and the decisions made. It is commonly accepted that there can be no room for counter-arguments when one resorts to the methods of science as the basis for justifying findings and recommendations. Albury & Schwartz (1982: 174) describe how misconceptions about methods of science and 'scientific' reports are exploited by some. They point out that one of the most powerful weapons used by industries and the state to defer, deflect, and discredit mass challenges concerning certain products, practices or research and/or industrial developments has been to cite official scientific reports - reports that state that the practices in question are perfectly safe or, failing that, are not more unsafe than say automobiles or, failing that the practices "are at the present time being studied." Albury & Schwartz (1982) mention that challenges in the case of asbestos, Agent Orange, or radiation poisoning, where it is painfully obvious that exposure to these events has caused birth defects, cancers and early deaths, have been discredited for not being 'scientific', that is, of not being produced in official government or 'reputable' industrial laboratories. Excessive faith in the scientific method can therefore result not only in the abuse of this method but also in the misinterpretation of its findings.

Scientism in science education can lead to a tendency to elevate school science over other subjects, thereby evoking a proclamation of scientific superiority. It can also foster an anti-intellectual attitude towards other disciplines. Science teachers appear to embrace an attitude that does seem to indicate a tendency to compare the intellectual value of each discipline. The following practice lends support to a suspicion that teachers consider science subjects of being of greater intellectual value. Top students are often channelled into the science discipline. By doing this, schools accord their students and the science subjects a higher academic status. Scientism, as practised in secondary schools, contributes to a false classification of school knowledge and accords differential status to the different subjects in the school curriculum. It also makes one form of knowledge appear more valuable and important than another. In some ways, scientism helps in the perpetuation of a socially stratified community. An individual's place in society is often dependent on the nature of his profession. Students recognise that different subjects are accorded differential status. Technical subjects and sometimes the humanities are placed on the lower rungs of the intellectual ladder. This becomes all too evident when lower stream students are channelled into these subjects. Such a practice in school finds support in the employment sector.

Science education has also been accused (Eastman, 1969) of presenting a picture of the irresistable power and automatic progress of science. A great deal of consideration is given to the accomplishments and products of science. There is a great deal of emphasis on the rhetorics of conclusion or 'valid' knowledge. In all branches of science, there is the "hard core of valid knowledge" (Ziman, 1980), and at every level, the teacher directs the teaching towards laying the foundation for the level above. All formal instructions tend to relate to the theoretical and factual aspects of science. When school science is taught in this manner, it cannot very well relate the view of science as indeterminate, probabilistic, and fraught with unresolved problems. Students can easily acquire a narrow view of science, especially the view that science can solve all problems, if science education continues to mention only the successes in the field of science.

Another consequence of the Methodological Reductionistic philosophy is the quantitative ideal - an interpretation of science based upon empiricism.

Quantification in science

The principle of quantification implies that whatever exists in nature must be quantifiable and the world must be purified of all mysteries and spirits in accordance with a mechanically oriented science (Smolicz & Nunan, 1975). It is said that quantification arises from the influence of the empiricist tenet that observation is the ultimate source of our knowledge of nature. The collection and analysis of large quantities of data are considered as the bases for verification. Every advance in science is seen as an outcome of meticulous observation and data collection. The empiricist influence has been such that scientific and sociological researches, in many instances, have become a purely empirical science with little consideration for the importance of imagination, speculation, intuition, and so on.

The evidence of the predominance of quantification in scientific activities can be found in scientific journals. Scientific articles are laden with data and data analyses. Such articles influence the type of research undertaken by post-graduate students and condition the young scientist to think in terms of empiricism. Ziman's (1968) position on personal and public knowledge of science indicates that both number and quantity play a fundamental part in what he terms the "rhetoric of science". Scientific papers with a liberal dose of mathematical equations and statistical data appear more impressive than those with only a few. While quantification is an essential part of science, too much consideration for this element of science draws attention away from the qualities characteristic of revolutionary science - creativity, imagination, intelligent guesses, expectations, etc. (Toulmin, 1972: 26-7). One often begins with this episode of science and then proceeds on to quantification for the purpose of testing the outcome of a speculative adventure. Kuhn (1977: 180) noted that "large amounts of qualitative work have usually been prerequisite to fruitful quantification in the physical sciences". Failure to recount how the initial ideas were formulated means that science students are less sensitized to the importance of the qualitative phase of a scientific activity.

Another implication associated with an overemphasis on quantification is the subsequent interpretation of scientific findings by non-scientists. Ravetz (1978: 277) states that when the scientist is functioning as an expert in the political sphere, he or she is generally expected to provide "hard facts", best expressed as precise numbers. Quantification becomes an accepted component of scientific research and is encouraged by political and industrial bodies that are increasingly funding scientific researches. Scientists are quite aware of inexactness, commonly called "error" in their experiments or observations but the general public and the politicians are often unaware of the degree of error. Quantitative assertions often require qualitative judgements of the inexactness (Ravetz, 1982) and because the problem of explaining the inexactness of a quantitative statement may appear too demanding a task, it is generally omitted. The end result is that political and technological debates may hinge upon or even be supported by empirical data whose factual content and accuracy are in question. While the politician or the technocrat may swear by the data, it is only the scientist who is cautious about relying too much upon empirical data which may contain a certain degree of inexactness. There is, therefore, an underlying danger in depending too heavily on empirical data. They may appear to substantiate a scientific statement beyond doubt and yet the scientific statement might itself be a mere conjecture or be based on false premises.

Another consequence of the quantitative ideal is the tendency to direct and judge human conduct in the light of empirical facts. This practice renders science the right to authorise and certify facts and pictures of reality in a purely mechanistic fashion thereby providing those in power with a scientifically legitimated procedure for treating humans and human conduct as numerical and quantifiable. All living things being studied are likely to be reduced to machine-like objects which have the property of being quantified. When the scientist is pictured studying man, he is seen as manipulating an object e.g., the astronaut when monitored physiologically by a scientist is pictured almost as a machine-like robot. The stress on quantification could well strengthen the stereotyped image of the scientist - an image in which the scientist is made out to be cold and impersonal. According to Smolicz & Nunan(1975), quantification where the human hand at work is ignored could result in the dehumanisation of the scientist because the scientist is made out to be "an abstract unit of analysis or a positivistic robot." Passmore (1978: 45) warns that emphasis on quantities and mathematical relationships rather than qualitative differences threatens individuality and impoverishes the imagination of those active in scientific research. However, quantification has a vital role to play in scientific activity but at the same time qualitative aspects should not be overlooked.

In school science, especially modern biology, there is an increasing trend towards the inclusion of mathematical and quantitative ideals (Smith, 1968). Quantitative ideals in biology are recognisable by the increase in the use of statistics and mathematical models. Current courses at senior high school level (see e.g., Dept. of Education, 1971) and textbooks (such as BSCS texts and Biological Science: Processes and Patterns of Life) stress the mathematical domain including statistical and graphical analyses. Form 7 N.Z. Teachers' Guide in Biology (Dept. of Education, 1971: 53) reveals the extent of the trend towards the quantification of school biology.

The N.Z. Form 7 Biology syllabus (Dept. of Education, 1971) states that

> Students should be familiar with the following ideas and techniques by the end of the course
>
> - randomness, change and probability
> - methods of data presentation, frequency distributions, graphs and tables;
> - simple differences between samples and populations, statistics and parameters....

The use of mathematical models and statistical analyses in the presentation and explanation of scientific phenomena is necessary and desirable. But they would be failing in their function if the purposes and limitations of these models and techniques are not fully explained. In the absence of a better understanding of the role of quantification, the relation of biology to man's reality of the world can be severely limited resulting in a mechanical conception of science. In view of the general dissatisfaction with current school science, quantification may worsen the move away from science subjects, because it makes science appear cold, mechanical and often too mathematical.

Reductionism in Science

Another emerging trend in the organisation of modern science curriculum is the emphasis on reductionism. Reductionism implies that everything in nature can be explained in terms of its parts. In other words, all scientific phenomena, animate or inanimate, are reducible ultimately to physical laws. This view has its roots in the positivistic thinking about the reducibility of scientific statements. Carnap (as cited by Hanfling, 1981: 107-9) speaks of the "reduction chains". He says that a scientific statement will be reducible to other scientific terms, and these in turn are reducible until we arrive at terms of the thing-language. The thing-language is what we use "in speaking about the properties of the observable things surrounding us" (p.107).

Carnap maintains that such terms as 'anger' are reducible to the thing-language in the same sort of way as, the terms of theoretical physics. He asserts that there is a unity of language in science viz. a common reduction basis for the terms of all branches of science. This concern for the reducibility of scientific statements has led to acceptance of the proposal that all biological phenomena can be reduced to physics and chemistry.

In his evaluation of the emphases placed on different levels of biological organisation by several traditional biology textbooks and the more modern Nuffield Foundation O-Level texts, Crossland (1971) found that, in the traditional textbooks, the study of individual plants and animals, their organs and tissues received greater treatment than other levels of organisation. However, in the modern Nuffield textbooks, the trend has been more towards the molecular and cellular levels of approach. Similar organisation of biological concepts can be found in the American BSCS projects. The BSCS blue version text examines the field of biology from the molecular point of view and the emphasis is upon the study at the sub-cellular level for understanding the organism in entity. The yellow version also stresses the cellular and molecular levels of biology and somewhat less on organs and tissues. Neilson (1974) in his analysis of the New Zealand sixth form biology textbook mentions the increasing emphases upon cellular and sub-cellular levels of organisation. Reiner (1968) points out that the two main characteristics of modern school biology are (a) that organic structure and function will find their explanation in terms of sub-microscopic units and (b) that all biological concepts can be explained by physical and chemical laws. These views of science have been found to be held by science students. For example, a set of questions relating to the concept of reductionism was administered by Barnett, Brown, and Caton (1983) to a group of zoology students.

This group was a representative sample of those learning biological science in 'western' universities and comprised third-year undergraduates, fourth-year undergraduates, honours students, and post-graduates. Barnett, Brown, and Caton noted that more than half of the 71 students held all biology to be ultimately reducible to physics and chemistry. The researchers believe that this concept of science is a consequence of text-books' emphasis on sub-cellular level biology and on narrow training. The students were being given a specialist training in biology with little knowledge of general biology.

The occurrence of the reductionistic view in school biology is indicative of the acceptance by curriculum developers and textbook writers of the following reasoning:

(i) that all matters obey the laws of physics and chemistry

(ii) that organisms are composed of matter

(iii) therefore, organisms obey the laws of physics and chemistry.

According to Neilson (1974), the influence of such a syllogistic argument is based on the assumption that, by analysis, the biological processes will become more basic and so lead to a simplification of concepts and principles. However, one may argue whether simplification is achieved by reducing biology to chemical and physical laws. The emergence of molecular biology has made biology much more mathematical and physical. Its language like the language of the physical sciences has become increasingly unnatural, precise, and mathematical. The danger is that like physics, it could lead to a decline in interest in biology (Holton, 1976).

Another reason for the confidence with which some regard biology as a complex of physics is the great success of quantum mechanics in explaining physical and chemical behaviours at the atomic level. This confidence is inherent in the writings of such scientists as Francis Crick. Crick (1967) hopes to be able to explain the whole biology in terms of the level below it and so on right down to the atomic level. His ultimate aim is to be able to give a quantum mechanical explanation of life, an explanation, therefore at the atomic level. However, it is quite possible that not all biological phenomena can be adequately explained in terms of atoms and their chemistry. Statements on (say) biochemistry often acquire significance only when they are related to the activities of the whole organism. It is nevertheless, a truism that all biological phenomena have physical and chemical components. But this does not mean that a more holistic explanation of a biological phenomenon can be derived by reducing this to chemistry and physics.

Sutherland (1970) points out that some biologists maintain that since the law governing the molecular behaviour of gases is reducible to the behaviour of the molecules themselves, then in the same way, the explanation of human behaviour, taking the brain as a physical system, is reducible to the quantum mechanical laws governing the behaviour of elementary particles. However, what we can say is that some phenomena have not yet been explained in physical/chemical terms. Whether they may be *explainable* (in future) is an open question. A person may believe in principle that they will be - but this is 'faith' not fact and has not been established. Some would rather argue that the molecular biologists' point of view fails to acknowledge the implications of mind or consciousness on organ systems. Although one can expect quantum mechanics to explain inanimate objects that are homogeneous, it is another matter to reduce the animate world to physical and chemical laws in order to seek explanations of animate objects. The manifestations of organic behaviour may not be reducible to explanations derivable from quantum mechanics alone. According to Wigner (1964), consciousness plays an important role. Men have minds and therefore the behaviour of human beings cannot be explained without reference to the state of consciousness. Furthermore, to regard man as a machine explainable in terms of the formal logic of physical theories, is to regard him as lacking the ability to make freely willed decisions or to determine his own actions by a conscious and rational choice. Both sides of the argument may appear somewhat dogmatic. It may or may not be possible to reduce biology and human behaviour to physics and chemistry. However, the anti-reductionistic argument reflects a genuine concern of the implications of reductionistic explanation of human behaviour.

According to Young (1976:57), school biology is increasingly being characterised by a reductionism to molecular levels of explanation because this is a reflection of much of the current research practice. Young believes that what is involved is not a viewing of man's consciousness as interrelated with his biology, but an essentially passive view of man increasingly subject to control by genetic and other experts. As a result, he fears, science education is progressively leading to a separation of pupils' everyday experiences from the range of inquiries and activities within the school.

Summary

An array of interrelated images/beliefs about science has been examined, and an attempt made to show that these images/beliefs reflect the influence of certain traditions within science education and within the 'philosophies of science' which is being interpreted as any/all belief systems about science, including assumptions that are not consciously held. Commitment to these traditions has meant that there has been a tendency to

(i) reduce the world to facts and quantitative abstractions;

(ii) project a value-free and neutral view of science and scientists;

(iii) have an excessive faith in the resolving powers of science and technology.

(iv) believe that biology and human behaviour are reducible to the laws of chemistry and physics;

(v) hold the view that the function of science is to facilitate man's domination of nature; and

(vi) maintain that science is a body of indubitable knowledge based on established facts from which conclusions are drawn by impeccable logic.

It seems, to some extent, that one of the reasons why most pressing social problems are not amenable to some sort of scientific resolution is the kind of science and scientists being perpetuated through myths. Furthermore, the common images of science and scientsts we hold are themselves inadequate and misleading. Also, the kinds of problems encountered in science education, such as the general dissatisfaction with school science, the fall in the numbers of students entering science, the lack of adequate scientific literacy amongst the general public, and so on may have their source in the nature of common images of science and scientists inherent in school science.

In the next Chapter, I shall examine several other features of science education: the major aims of science education, teachers' understanding of the nature of science, paradigmatic indoctrination through standard problems, exemplars and practical work, and specialisation. I shall attempt to show that these have their weaknesses and as a result they also contribute to some of the problems associated with school science - problems that have been discussed in the earlier chapters.

CHAPTER FIVE

INADEQUACIES IN CERTAIN OTHER FEATURES OF SCIENCE EDUCATION

In the earlier chapters I discussed how commitment to certain philosophical/methodological orientations has resulted in a particular way of viewing science and the scientist. It has been argued that the resulting views and the practices based on them are dysfunctional because they have been found to contribute to misunderstandings about the nature and functions of science and its 'process' aspects. Because of such inadequacies, science education generates its own problems, as indicated earlier.

In this Chapter I shall explore certain other features of school science, in particular, schools' perception of the purposes of science education, the practice of specialised science education at the secondary school level, and teacher attitude towards, and understanding of, the nature of science. In considering these issues I shall attempt to point out some of the inadequacies inherent in them. In order to achieve this I shall:

(i) identify the major goals of science education and then show the kinds of problems they give rise to;

(ii) argue that current science education is to some extent a dogmatic initiation into a particular paradigm, which while successful as a means of producing future paradigm-bound, 'normal' scientists, fails to develop students' creativity and fails to make science teaching as educationally effective as it ought to be;

(iii) consider the deleterious effects of the fragmentation and compartmentalisation of school science; and

(iv) examine teacher attitude and understanding of the nature of science, in order to show that misconceptions about science and problems associated with science education are exacerbated by teachers' own attitudes and their understanding of the nature of science.

I believe that all the above issues and those considered in the earlier chapters are closely related, thus often it is unavoidable that argument/discussions should overlap to some extent. Consequently, there is a fair amount of argument which is common to a number of issues considered.

The major goals of science education

Problems associated with science education are not solely due to implications of 'Methodological Reductionism' as earlier outlined, although this plays a major role. There are, however, other factors. For example, the conventional and/or officially stated aims of science education are equally important for consideration, because they influence what should be taught, how it should be taught, and to what groups of pupils and for how long.

Therefore, it is possible to link some of the inadequacies inherent in school science to the aims which prescribe the direction a particular curriculum development should take. To identify the dominant strand of thinking about the purpose of science education, it is necessary to provide a brief review of the development of modern science programmes, for within such programmes one can recognise the factors influencing current science.

The nature of the 'first generation' science programmes during the sixties was markedly influenced by the then existing climate of international tension and competition, engendered by the cold war. Salomon (1977: 51-2) noted that the period 1957 to 1967 was highlighted by strategic concerns in which military objectives prevailed over all others, and there was a concern for research and development efforts to produce a better economic pay-off. With such an economic and political atmosphere compounded by the launching of the first Soviet spacecraft, the situation was favourable for innovations in science education. Consequently, there followed a huge and hurried effort of financing and developing new science curricula. The United States National Defence Education Act (Wynn & Bledsoe, 1967; Tisher, Power & Endean, 1972) administered through the National Science Foundation, made possible the provision of enormous sums of money to develop science courses and associated materials. In both the U.K. and U.S.A., state investment in science education expanded dramatically. For example, in the United States the National Science Foundation budget increased from U.S.$3.5 million in 1950 to $159 million in 1961 and to $435.7 million in 1969 (Ronnenberg, 1970). A large portion of the N.S.F. budget, for instance 92.5% in 1969, was used to improve and advance basic research and education in the sciences. This massive investment meant that the state assumed greater influence over the financing, packaging, and transmission of scientific knowledge. Consequently, the aims of science education were influenced by state policies on the future of scientific and technological activities.

The 'first generation' science programmes developed during the late fifties and sixties were:

PSSC: Physical Science Study Committee, 1960
CHEM Study: Chemical Education Materials Study, 1963
CBA: Chemical Bond Approach, 1963
BSCS: Biological Science Curriculum Study, 1959
HPP: Harvard Project Physics, 1964.

In New Zealand (Malcolm, 1979; Renwick, 1980), as in several other countries, in the late fifties and sixties, priority was also given to curriculum development in science. The political philosophy of the time led to the importation of the abovementioned programmes into New Zealand. The PSSC project was adopted as it was, while in the case of BSCS projects, there were modifications to suit New Zealand conditions. As for chemistry, there was resistance to straight adoption (Malcolm, 1979), but the New Zealand curriculum was prepared along similar lines to the American projects, and the American texts were used extensively.

The hope of everyone involved in secondary school science reforms was to see the resurgence of scientific knowledge, not merely as part of a common culture but as a means of increasing the number of technologists and scientists. The revised programmes in the U.S.A. were intended to build up scientific and economic manpower by bringing modern scientific concepts, methods and knowledge to the nation's public schools. Legislators and military men (Rees, 1975) were convinced that such a move was essential if the country were to maintain itself in competition for military security and in the material well-being of the people. West (1976) noted that reforms were undertaken in the hope of producing a small but ever increasing number of able boys and girls who would read for degrees in science and technology as a step towards professional careers in pure and applied science. Because of commitment to this aim, school science education became interlocked with university science, with one seen essentially as a preparation for the other, and both having strong vocational and professional objectives (McConnell, 1982). Much of the secondary school science were thus designed to meet the needs of the academically-able students. According to Nelkin (1977:33) and Baez (1976:79), science education satisfied very well the needs of the elite who would go on to specialise in science. For all intents and purposes, the concern was not for the individual student but for the maintenance of the supremacy of western science and technology. Since many of the science curriculum projects of the sixties and even the seventies were designed for university-bound students, they failed to generate any significant improvement of scientific literacy among the general public (McConnell, 1982; Gonzalez, 1983). The tradition of the science education of the sixties and seventies is still existent today, not only because many of the original programmes are still in use (often in modified form), but also the N.S.F.-sponsored science projects carried such an aura of prestige that they have tended to set the pattern for other science texts currently in use. In addition, there have been no universal reforms in science curricula on the same scale as those of the sixties.

A science programme that is designed to meet the needs of those scientifically oriented at any one particular level, generates its own problems. The manifestation of these is evident in students' complaints about the subject being 'difficult'. This is brought about in the following manner. When a curriculum is developed so as to be academically challenging and interesting to a minority then, quite often the majority will find it exceedingly difficult, uninteresting, and very academic. Such appears to be the problem that plagues secondary school science. The following studies reveal the existence of the difficulty problem and how this problem has a negative effect on students' attitudes to science. Selmes, Ashton, Meredith and Newell (1969), in their discussions with senior pupils in English schools, found that students complained about the difficulty of physical science. In New Zealand, Tasker, Freyberg & Osborne (1982) working with students in Forms 1 to 4 found that the children complained that scientific ideas and theories, of the current school science, were difficult to understand.

In the United States numerous studies, to mention a few: Edwards & Wilson (1958), Pheasant (1961), Lowry (1967), Johnstone & Sharp (1970) and Choppin (1974), concerning the decline in interest in school science, have been carried out. Some of these (Ronnenberg, 1970; Silbermann, 1970; Uzelac, 1973; Stronk, 1974 and Clish 1975) have linked the decline in interest with students' perception of science being complex and difficult. In England, Dainton (1968; 1971), Newell (1969), Meyer (1970), Fairbrother (1975) and Pell (1977) have attributed the decline in the popularity of science subjects to students' perception of science as being factually and conceptually difficult.

This problem is of some concern because early in life, pupils do show interest in science. It is only when they come in contact with senior high school science that a significant majority are actually alienated from science. Brown & Davis (1973) in Scotland, Meyer & Penfold (1961) in England, and Wynn & Bledsoe (1967) in the United States found that there was definitely no relationship between interest in science, and intelligence. In other words, science broadly conceived, is of interest to pupils of all ages and levels of intelligence. But it may be because many science curricula are designed to conform to the needs of those who are scientifically oriented (especially those who have a preference for syllabus-bound science) that alienation from science among a majority of students, has been so pronounced. Interest in science has been noted to decline when science is perceived to be difficult.

But why is science perceived as being difficult? One possible reason can be traced back to those who designed the science programmes and what they considered to be important as part of science teaching. The projects were dominated by science specialists, who were not teachers but science experts from the universities. It was the era when scientists were held in high esteem; for were they not responsible for bringing about the victory for the Allied Forces through their participation in the Manhattan Project and in many other ways? They knew from their own experience what science was, its content and its structure. It was axiomatic to them what was to be taught. Whether it would be possible to teach what they prescribed to students who were still in the process of intellectual development, was not seriously considered. The structure and method of science and the content of science were things they emphasised. In the structure, they saw science as a set of distinct disciplines: physics, chemistry, biology. For content, they saw science as a set of unifying principles by means of which it was possible to make intellectual sense out of a wide range of experiences in the physical world. The result of these projects with their strong emphasis on the principles of science, was that students were unable to cope with the material because concepts were being introduced at too early an age (Flowers, 1967; Wells, 1971). In other words, complex concepts were being introduced before the student had developed a general capacity to solve abstract theoretical problems. Moreover, the treatment was largely didactic despite the fact that many programmes had incorporated the enquiry approach. According to Sadler (1982), curriculum developments in the 1960s (particularly in the sciences) emphasised learning through discovery and inquiry. The idea gained wide acceptance and became a major curriculum thrust. However, the movement produced fewer enduring changes in science classrooms than its proponents had hoped. The true spirit of inquiry which curriculum developers had sought to generate had all but evaporated from the classrooms. The traditional teaching approach continued to be used and this was intellectually stimulating for only a few, but non-challenging and uninteresting for the majority. As a result, school science failed to stimulate the interest of a large proportion of the students.

One of the most important problems associated with the failure of the 'first-generation' science programmes and dissatisfaction with current science education is that of language. The language of the curriculum (Groundwater-Smith, 1982) is often its most neglected feature, particularly where that language is highly specialised and where the 'clients' have fundamental communication difficulties. Several studies in readability of science textbooks (see Harrison, 1980) in use in the U.S.A. and U.K. have revealed that over half the secondary school pupils using the textbooks could not read them profitably. Yager (1983) analysed 25 of the most commonly used science textbooks (including Modern Chemistry by Metcalfe, Williams & Castka and Modern Physics by Williams, Trinklein & Metcalfe) in U.S. high schools in terms of the occurrence of special/technical words. He found the number of words used at every level to be considerable - often more than would be required if a new language were introduced. In addition, he found that the number of new words in science often approaches the total number that could be expected in terms of total vocabulary increase at a given class level for a given student. For students, for whom English is a second language, the problem is even greater. Not only the English language - ordinary and specialised - is foreign but there are difficulties resulting from mother-tongue interference with readability in the English language (Jegede, 1982). The overall result (Groundwater-Smith, 1982) is that students have an inadequate grasp of various concepts principally because the language of science gets in the way of understanding scientific facts and ideas. According to Tasker, Freyberg & Osborne (1982) the difference in meaning between scientific language and everyday language has resulted in confused conceptualisation. Yager (1983) maintains that "one major fact of the current crisis in science education is the considerable emphasis upon words/terms/ definitions as the primary ingredient of science - at least the science that a typical student encounters and that he/she is expected to master" (p.577). Pauling (1983) is critical of not only the level of language but much else. He states that current college and secondary chemistry texts contain far more information than any student could be expected to learn and to understand in one year. Moreover, much of it is presented at so advanced a level - yet at the same time superficially - that it could hardly be understood by a beginning student. He claims that today's chemistry textbooks serve to turn interested students away from chemistry instead of attracting them into the field.

Another reason for the difficulty that students have with science has been attributed to the frequent use of mathematics in science. Meyer & Penfold (1961) found that difficulty with mathematics is one of the deterrents against students selecting science subjects at senior high school level. Although mathematics has increased the power of science as a mode of intellectual inquiry it has generated problems associated with teaching and learning. It has become a tradition of science teaching to translate scientific problems into disembodied symbols of mathematics. The adverse effect of too much mathematics in physics, besides activating greater discontent with the physical sciences, is the continued danger that abstract symbolism may weaken the connection of science with practical affairs and technology. Layton (1973a) states that the direction of scientific enquiry is increasingly towards pure mathematics, "making facts of nature mere pegs on which to suspend festoons of algebraic drapery" (p.20). The ability to translate aspects of concrete experience into some form of symbolic representation, and then to reason on this at an abstract level, is rarely found in school students. Thus, there would appear to be natural limits on children's understanding of abstract scientific ideas. Any change in school science into a general education is hindered by the generally accepted view that the prime purpose of science education is to prepare students for careers in the field of science and technology. Theorists in science education consider academic excellence with a high level of knowledge as an integral part of science education and often they see efforts to simplify concepts and to reduce the amount of mathematics, as a dilution of school science.

The difficulty issue poses a dilemma for science educators. Many science educators, according to Michael Young (1976), believe that the nature of science and the concepts in science are themselves complex, and therefore only the minority can be expected to cope with school science. Failure in academic science by many students is explained away in terms of the accepted belief in the complexity of scientific concepts and/or in terms of the assumed lack of scientific ability in the pupil. Such educators appear to accept the status quo and for them there is no strategy available to minimise the difficulty problem. They accept that since science is inherently difficult, only those who are scientifically oriented can be expected to cope with such subjects as physics and chemistry. There are others, like Layton (1973) and Bondi (1975a), who believe that much of science, especially physics, is complex and abstract and this very nature of science makes it difficult to learn. Such educators would like to see science made attractive "*because* it is difficult, not made attractive *although* it is difficult" (Bondi, 1975a).

It can be seen that the original thinking about modern science curricula is well supported by the theorists who consider science education to be one of inculcation of factual and conceptual knowledge. Whatever changes that have taken place so far have been influenced by a desire to make science more attractive for those assumed to be scientifically oriented. Current science education continues to follow the tradition of the 'first generation' science programmes. An extensive survey carried out by Harms & Yager (1981) reveals that:

1. there is a mismatch between the science curricula found in schools and that which 90% of the students want and need;
2. nearly all science teachers (90%) emphasise goals for school science that are directed only toward preparing students for the next academic level (for further formal study of science);
3. over 90% of all science teachers use a textbook 95% of the time; hence the textbook becomes the course outline, the framework, the parameters for student's experience, testing, and a world view of science; and
4. there is virtually no evidence of science being learned by direct experience.

Bondi (1975a) quantifies the present situation by stating that the proportion of science students destined for academic science is less than 1% and, therefore, "it is surely not right that we should model the education of 99% to any extent by the needs of 1%. We must not forget that 1%, but we must not be dominated by its needs" (p.472). One of the current problems is that science lacks a more comprehensive framework - a framework that can accommodate the two important features of science, that is, science as an intellectual pursuit and science as a cultural activity.

Another area of contention is whether science education should be merely a paradigmatic indoctrination through standard problems, exemplars, and mechanical practical work in order to produce 'normal', paradigm-bound scientists. The stand taken here is that because of the heterogeneous nature of student ability and intellect it is more beneficial to design science programmes that foster independent thinking and build up students' confidence in their own abilities rather than have programmes that foster a passive and unquestioning acceptance of a particular view of science.

Exemplars, problems, and practical work

The orthodoxies of science teaching as exemplified by the types of problems, exemplars, and practical work seem to have great appeal for curriculum writers and science teachers. Science textbooks, in general, appear to be geared to the inculcation in the student of the dominant scientific paradigm of the day. The nature of the problems and exemplars found in textbooks are indicative of science educators' commitment to the reigning paradigm that produces a consensus of opinion on what young science aspirants should be taught. Students are presented with standard problems based upon exemplars which Kuhn, (1970a: 187) defines as "the concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, on examinations, or at the ends of chapters in science texts." By and large, science textbooks are not designed to encourage either questioning or critical scrutiny; they are designed as to empower the student to master the techniques of the relevant paradigm. Kuhn (1963) maintains that science textbooks/teaching have remained "a relatively dogmatic initiation into a pre-established problem-solving tradition that the student is neither invited nor equipped to evaluate" (p.351). In other words, science education inculcates into the students what the scientific community has previously gained - a deep commitment to a particular way of viewing the world and of practising science in it.

The tradition of fact-laden, content-oriented structure of school science is a result of the overall aim of science education, that of producing a minority population of competent researchers. According to Kuhn (1962), the major aim of science education has been to train good 'normal' scientists, that is, competent paradigm-bound puzzle-solvers. He further claims that the most successful way to produce competent puzzle-solvers is to de-emphasise their critical powers and inculcate in them the narrow and rigid orthodoxy necessary for paradigm-bound research. Kuhn supports his claim with the observation that most researchers are involved in normal scientific work. The scientific community is, at most times, trying to solve puzzles resulting from an attempt to see the world in terms of a single paradigm or a closely related set of paradigms. This being so, the dominant view of the world dictates the types of problems, exemplars and methods to be utilised. Therefore, it is argued that young science aspirants need to be involved in a similar practice if they are to become paradigm-bound researchers. This argument of Kuhn's is supported by Jevons (1975) who also believes that science students need an established framework in order to acquire the power to solve problems in the same way as normal science is usedto solve problems. Thus, in the view of Jevons, a dogmatic element in teaching science becomes unavoidably necessary. He maintains that it is unrealistic to expect students to criticize or create theories without first having acquired basic goundwork in science. However, a student does not need to acquire basic groundwork in science to be able to develop and practise the skill of criticizing and creating theories (hypotheses, guesses, or simple ideas). Criticism and creativity can be practised on the basis of existing knowledge and experiences - this point will be developed further in Chapter 6. Kuhn (1963) offers another reason for supporting the tradition of a highly structured initiation in school science. He reasons that nature is vastly complex to be explored at random and so a dogmatic initiation is necessary in order to guide the student where to look and what to look for.

Kuhn's view of the 'normal' science as the essence of science and of the consequent methods of instruction based on this, have provoked some criticism. Watkins (1970: 274) after first dismissing normal science as hack work and an exercise fit only for plodders, later questions its very existence for, in the form in which it is described by Kuhn it is so conservative and makes the scientific community such a closed society that it would never give rise to revolutionary science. Popper (1970: 52-3), on the other hand, agrees that normal science does exist but considers it as an activity of "the not-too-critical professional /and of the/ science student who accepts the ruling dogma of the day". Students trained in this manner may seldom take the initiative to take a critical approach to question the very theories upon which their works are based. The rigidity of the dogmatic approach of the normal method of science may stultify students' own creativity and may suppress their confidence in making bold conjectures. Although a normal scientist's work may not involve the type of creativity and bold conjectures one normally associates with revolutionary science, it is nevertheless highly complex, intensive and imaginative. Consider, for example, experimental design, hypotheses formulation, data interpretation, sophisticated instrumentation, intricate experimental work, and problem identification and isolation - these all require a fertile and versatile mind. A normal scientist's activity can therefore be highly imaginative, creative and complex. Furthermore, normal scientific activity is an essential part of science. It is often through this type of activity that anomalies are encountered.

Pippard's (1972) view of science education is somewhat similar to Kuhn's. In brief, what universities and schools attempt to do is to turn out future researchers whose ideas are close to those of their mentors: a succession of technically accomplished performers well groomed in the current scientific theories but ignorant of society and its needs. According to Pippard, scientific principles and laws are taught as an end in themselves. The methods adopted to inculcate these in the pupils involve not only the theory, not only the verbal instruction, but also a "fine collection of standard problems to which the laws can be applied to give the right answers" (p.5). And,however artificial these problems may sound to the uninitiated, students who have been exposed to that sort of thing for some time fail to notice how artificial they are. What this means is that students are socialized to see things through the eyes of their mentors whose particular view of the world they have assimilated. Here Pippard is referring to that component of Kuhn's paradigm to which the label of exemplars has been given. In Kuhn's view concrete problem-solutions are not simply there to provide students with practice in the application of what they already know. They are also there to increase the problem-solving skills of students and to help them acquire skills of seeing a variety of situations as like each other, as subjects for the same symbolic generalization, such as $f = ma$. After the students have completed a certain number of problems according to a particular symbolic generalization they are supposed to have acquired the knowledge and skills of their mentors (also refer to Smolicz, 1974).

Pippard regards such problem exercises, although valuable and in fact essential, as merely a rigorous mechanical exercise. They help to reinforce convergent thinking but do not provide the opportunity nor the skills for divergent thinking. The difference between Kuhn and Pippard is that while the close fit between his theory and the actual experiences of scientists gives Kuhn grounds for believing the immense effectiveness of this type of education, Pippard (1972: 7-12) disagrees with many of its aspects. For, in his view "too much emphasis on problem solving where the answer is provided at the end of the book obscures certain important aspects of real physics, which we fail to teach as competently as those already mentioned". For example, because many of the physical problems are mathematically intractable "we [scientists/science educators] resort to guessing and insight... far more than one would infer from looking at the syllabus of a physics course... [yet] we never seriously tried to devise techniques for teaching people how to make reasonable guesses". There are other ways in which our current teaching is deficient. For example, in 'real' physics, scientists frequently encounter problems which clearly have an answer but where one does not have any indication of how to start working them out. They may have to rely on qualitative observations "on the intuitive feelings for what can and cannot happen". In Pippard's opinion, it is this type of intuition which is the mark of a sound scientist and it is also a quality which is "not developed by concentration on the laws and their exact application" (p.12).

There is a contrast between Kuhn's implied, but limited approval of the present system and Pippard's idea. Kuhn maintains that although scientific training is not well designed to produce the man who will easily discover new ideas and theories, it will nevertheless turn out scientists who for the purposes of normal-scientific work are almost perfectly equipped. On the other hand, Pippard's plea is for the need to develop a "fascination for... all the marvelously complicated things that can happen, that are worth looking at and speculating about even though one knows an exact analysis is not practicable" (p.12). Pippard's conclusion is that it is this side of a scientist's life that is the "spring of his imaginative originality" and that by neglecting to develop it"we are losing a great educational opportunity" (p.12).

The nature of tests and public examinations determines to a large extent how a particular subject should be taught. Currently, many public examination papers in the science subjects show a commitment to the paradigm of the day through the types of questions they ask. There is a set pattern of questions asked. This practice encourages rote learning and fosters a formal and restricted understanding of science. The N.Z.U.E. Physics and Chemistry Examination papers are examples that illustrate how exams reinforce and sustain a view of science that is largely formalistic, academic and socially-isolated. An examination of past papers in these U.E. subjects will reveal the influence of an accepted tradition in the types and structure of questions asked over a period of several years. Teachers and students are often quick in recognising the trend and so subsequent teaching and learning become somewhat like a rigid inculcation of the paradigm of the day, reinforced by a rigorous practice in solving problems from past exam papers. This style of teaching and learning has become so widespread that textbooks such as J.W. McLaughlin's Sixth Form Chemistry, Notes and Examples (see Eames, 1981, for the extent of its usage in New Zealand schools) and a similar textbook on physics by the same author are now used as class texts. These books provide very concise notes on each of the topics from the syllabuses together with appropriate exemplars and selected U.E. questions from past examinations. Presumably the McLaughlin books would not have been adopted and retained so widely unless they were seen by the relevant teachers as providing a means to success for students in U.E.-related examinations.

Practical work also reflects a tendency to inculcate in the student the paradigm of the day much more than promoting independent thinking and developing critical thought. Sometimes emphases on tidiness, on proper writing style (based largely upon the writing styles of experimental reports found in research journals), and on general behaviour in the laboratory become so important that the purposes of carrying out a particular investigation are lost in quagmire of rules and restrictions. It is often said that experiments are being performed according to a careful set of instructions which sound more and more like recipes from a cookbook. Getting the results is all that matters and consequently the interpretation of the results in terms of the conceptual knowledge is often overlooked. It appears that the direction of practical work is more towards acquisition of manipulative skills (although this is an essential part of science education) rather than the development of a better understanding of the relationship between experiments and theories, to design experiments, to develop a scientific way of working, or to encourage thought-provoking discussions based on practical work. According to Tasker, Freyberg & Osborne (1982) and Woolnough (1983), the purpose of experiment is vaguely seen by the teacher. They noted that students had no clear perception of what they were investigating nor did they clearly understand the purpose of the experiment.

Science syllabuses and textbooks stress that the full worth of scientific knowledge "will become apparent when you see it in relation to the field and laboratory investigations you will be engaged upon. In these investigations you are working as a scientist as you seek your own answers to the problems posed by living organisms" (Dept. of Education, 1973: xi). While it is possible to agree with such statements on the purpose of practical work it is difficult to perceive that the student is working as a scientist. The student is not actually 'doing science' when learning or performing some practical work. "Rather the student is learning selected scientific facts.... He remains the apprentice not the craftsman" (Matthews, 1975: 159). Practical work is not seen by most pupils as a way of experiencing the excitement of personal inquiry but rather as the following of a set of instructions to achieve the expected results and the right answer (i.e. the teacher's answer).

The present tradition in school science reflects a commitment to the belief that students need to master the fundamentals before their imagination can be let loose on problems more meaningful to them. While it is true that students need to acquire appropriate scientific knowledge before they can be either critical or creative within it, it does not mean they should be denied the opportunity to develop creativity or a critical attitude. As Stenhouse points out (1971: 177): "It seems often tacitly to be assumed, however, that the causal factors of an individual's cognitive style and personality can operate in a neat temporal succession, the non-conformity of a discovery and innovation phase in adulthood being preceded by a docile acceptive phase in the teens and twenties". It is quite possible, taking into consideration students' own experiences and knowledge, that they are capable of being imaginative and creative at all stages of their secondary school life rather than later in life.

The rigidity and the restrictive nature of current science education make science appear artificial when students are required to solve problems - problems whose solutions are derivable. Artificiality is conjured in the following manner. Where a particular problem is found difficult to solve it is often avoided in the subsequent years and where an experiment is found not to work in terms of the expected result then such an experiment is discarded. Often experiments with live and mobile animals are rarely performed because such experiments are considered difficult to carry out and because animals do not 'behave' according to standard textbook requirements. Sometimes animals may be used in laboratory experiments, other than for dissection experiments, but they are often so completely out of context of the habitats in which they have evolved that it makes the exercise biologically meaningless. The differences in behaviour of animals being studied under laboratory conditions in comparison to their behaviour in the natural state, are seldom pointed out to the students. According to Malvern (1977), one possible source of pupils' misconceptions about the nature of science is practical work - practical work that are poorly planned, inflexible, inadequately explained and lack a theoretical framework.

The commitment of science educators to the goal of producing normal, paradigm-bound future scientists and technologists has resulted in the design of science courses that are basically an initiation into a pre-established problem-solving tradition. As a consequence, misunderstandings about the nature of science and scientific methodology are reinforced. In addition, science education fails to develop certain attitudes and habits of thought considered necessary for revolutionary science. The inadequacies in science education are further complicated by the narrow disciplinary approach of modern science programmes - an approach that is influenced by a consensus of opinion. There is common agreement that the primary goal of science education is to produce specialists in different areas of pure and applied science.

The classification of science

Classification, in the present context, refers to what Bernstein (1971) considers as the degree of relationship between different science subjects and not to how the content of each science subject is organised. The impetus for the separation of science subjects into different disciplines was provided by the 'first generation' science projects. Although there is a long tradition of fragmenting science into separate subjects, one need not look beyond the inception of the modern science courses of the sixties for the reasons. The 'first generation' science programmes set the pattern that has now become so ingrained that recommendations for the integration of the sciences are not so readily accepted. According to Tisher, Power & Endean (1972), each of the National Science Foundation-sponsored projects (PSSC physics, BSCS biology, CHEM Study and CBA chemistry) involved the cooperation of subject-based scientists, educational psychologists, evaluation and curriculum specialists - with the scientists calling the tune. Because of the influence of subject-based scientists, discipline-oriented packages of scientific knowledge were produced. Hurd (1970: 57) noted that each course was developed independently of all other courses thereby helping in various contents being well insulated from each other. The individuals that participated in the production of the first set of N.S.F.-sponsored texts, for example the chemistry texts, were either chemists or educational specialists but not physicists, biologists, historians, philosophers or social scientists. The materials produced were subject-wise well insulated (Layton, 1972). In addition, the 'first generation' science textbooks were written to conform to the needs of single science enthusiasts - chemistry for chemists, physics for physicists, biology for biologists (Malcolm, 1979). This came about not only because of the involvement of discipline-oriented scientists but also because of their views on the structure of science curriculum. It was maintained that the content and learning experience should reflect the underlying structure of each scientific discipline separately. The major emphasis in each of the science courses was to introduce students to key concepts and principles of that particular science subject. Arguments then offered and which are still being offered to justify specialisation in school science are: (i) the quantity of knowledge currently available is such that conceptual compartmentalisation and attendent specialisation are both understandable and, in some respects, essential; (ii) curriculum developers, especially in the physical sciences, believe that weakening the boundaries between the disciplines could possibly lead to a contamination and dilution of each subject. Both arguments appear to be based on the assumption that teaching of science means to inculcate factual information in the student. The argument would be acceptable if teaching were merely knowing facts. However, it is more than knowing facts, it includes understanding of principles, fostering of certain attitudes and habits of thought, and so forth. If science education at the secondary school level can be perceived as a general rather than a specialist education then the fragmentation and specialisation could be avoided.

According to Koertge (1969-70), specialisation cannot be supported by the nature of scientific knowledge. He maintains that since science is progressing towards a more comprehensive and unified structure, at the conceptual level, it should become easier, not more difficult, to find one's way round the necessary mass of facts. For example, there has been an enormous increase in the number of known organic compounds in the last twenty-five years, yet organic chemistry is more tractable today than before because of significant developments in the theory of organic reactions and reaction mechanisms. So a case can be made out for less specialisation at the secondary school level.

There are certain disadvantages resulting from a continued call for specialisation at secondary school level. For example, the single discipline-based sciences have led to the study of each subject in complete isolation from each other (Ahmed, 1976). Chemistry, for instance, provides no support for physics, and physics is made to appear as if it has little relevance to chemistry. Neither of these branches of science display much connection with the biological sciences except in the area of molecular biology where attempts are made to relate chemistry to biology. When efforts are made to integrate the sciences it often ends up, in the opinion of Tricker (1967: 12), as "little more than patchwork quilt stitched together of different subjects". The end result of specialisation is that it promotes a separate, piece meal view rather than a composite view of science in theory; and in practice it discourages the kind of broad-based interdisciplinary studies which can uncover the necessary evidence that cannot be derived from single science studies. According to Churchman (1953), strict disciplinary thinking erects formidable barriers to the arguments, methods, and data of other disciplines thereby insulating a particular piece of work from the strongest possible challenges that could be mounted against its most basic concepts. In the opinion of Young (1976), "it is inescapable that most of those who become 'successes' in school science are systematically denied the opportunity to grasp science as an integral and inseparable part of social life .... The 'failures', equally systematically, leave school to become part of the mass of scientific illiterates...." (p.53). Here Young is not merely advocating the integration of just the sciences but is suggesting that science needs to be taught in terms of its social context - a multi-disciplinary approach.

The fragmentation and compartmentalisation occurring in school science could have a deleterious effect on student's attitude towards science. When science is separated into physics, chemistry and biology, students' view of nature and how this relates to their environment are accordingly separated. Alienation creeps in because, with specialisation, knowledge becomes packaged in isolation having little or no links with the learner or with his world. From the sociologists' point of view, e.g. Young (1976, 1977), the separation of the sciences is not seen as a consequence of some objective dichotomy of the reality of the world but a separation in keeping with the separation found in the social order. School science is thus alleged to be reinforcing the division found in the social system. This contention finds a certain degree of support in the overall aim of science education, that of providing a constant stream of young aspirants who would take up specialist careers in the field of science and technology. It may be true that school science reinforces the division found in the social system but the possibility exists that this is not a conscious or deliberate act but a result of unconscious beliefs and assumptions about education as a whole.

There are also practical reasons for suggesting that specialisation at the secondary school level is unwarranted. One reason is, keeping in mind that there is little communication between textbook writers, curriculum writers and those who develop the syllabuses of the individual science subjects, that there is a certain amount of duplication. For example, topics (at the S.C. and U.E. levels) such as kinetic theory of gases are covered both in physics and chemistry. Biology contains topics such as capillarity, osmosis and fluid pressure which are also covered in physics and/or chemistry. Duplication can be avoided with an integrated science subject. Next, taking into the consideration the number of periods per day and the maximum number of subjects a student can handle in any one year, the need to study three separate science subjects limits the science student to a very narrow selection of subjects. In a situation where a student has undergone several years of a heavily science-biased education he may find that his interest lies elsewhere or that he is not scientifically or technically oriented. The decision to change to some other field of study could be unnecessarily obstructed because of a rather narrow and specialised base. Specialisation as a result of the separate sciences at the secondary school level denies the student an opportunity to study a wide variety of subjects.

Teacher attitude and understanding of the nature of science

An examination of the inadequacies in secondary school science education is incomplete without considering the teaching qualifications of teachers, their attitudes towards science education, and their understanding of the nature of science. The success of any science curriculum is dependent upon teachers' attitude and competence. In the next few pages, I intend to show that there are teacher deficiencies in certain areas, which contribute to the problems associated with school science. Studies by Miller (1963), Schmidt (1967-68), Welch & Pella (1967-68) revealed that many secondary school science teachers' understanding of the nature of science was no better than that of their students, while Carey & Stauss (1970) found that many science teachers did not understand the nature of science well enough to teach it as a conditional inquiry. Koertge (1969-70), in his own experience as a teacher of philosophy of science , noted that science teachers "had little explicit knowledge of the structure of their subject.... For example, although they had all studied both Boyle's gas laws and the kinetic theory of gases, they could not easily state the relationship between them". Osborne (1983) found that some teachers had difficulty in teaching certain physical concepts. But this does not mean there aren't teachers who are competent and possess a good grasp of the subject(s) they teach. There are many dedicated teachers and yet there are some whose effectiveness is limited as a consequence of inadequacies in their professional training programmes.

It has been discussed, in the previous chapters, that some of the problems confronting science education stem from misconceptions about science. Since teachers are actively involved in the teaching of science, either they are aware or they are unaware of these misconceptions. If they are aware of the myths and misconceptions about science then, it can be assumed, that they are taking steps to demythologize science. If they are unconscious of the nature of misconceptions then misconstrued ideas about science are being perpetuated. The nature of the current problem suggests that a good grounding in the philosophy and history of science is vital for science teachers. Robinson (1969: 99) made the observation that "the level of preparation at the bachelor's degree in the sciences does not provide the prospective teacher with the necessary philosophical background upon which a philosophy of science teaching consistent with the nature of scientific knowledge may be developed". Similarly, Stenhouse (1972) and more recently Yager et al. (1982) have pointed out that the present day problems have resulted from decades of neglect of the essentially philosophical issues.

Another area of importance in the success of teaching of science is teacher attitude and practices especially in relation to what teachers consider to be the important aspects of science education. Gardner (1975) found that teachers regarded cognitive outcomes as more important than affective outcomes. According to Young (1977: 251), it appears that teachers' attitude and practices sustain a view of science as "things to learn, a body of knowledge external to the learner which is experienced as alien to them both". Alienation often results when teachers discard 'non-subject' but scientific, technological and everyday knowledge which pupils have. Sometimes this problem can be attributed to constraints imposed upon teachers by the demands of the syllabus. Teachers often find themselves in a rather unenviable situation. They are forced into transmitting knowledge circumscribed by a particular syllabus which maintains a clear distinction between academic (usually part of the syllabus) and non-academic (usually not a part of the syllabus) science. Such a system fails to allow the student to relate his/her knowledge and experiences to academic science.

According to Stenhouse (1972): "Everyone pays lip service...to the notion that teaching leads to understanding principles rather than knowing facts - in practice the teaching of science, despite recent advances remains largely a matter of imparting factual information. Or rather, information is imparted as though it were factual, when much of it really is not" (p.204). A similar point has also been recently made by Renwick (1980), Olson (1982a: 180) and Tasker, Freyberg & Osborne (1982). They point out that much of the teaching is still content-oriented. One possible reason for this is that teachers have difficulty in breaking away from the way they themselves were taught. What is often internalised unconsciously influences ones own teaching practices. It probably boils down to how teachers were taught, what they were taught, and what they were not taught. When looking at the pattern of their progress through various stages of their education, it would be found that most teachers have passed successfully through the different levels of formal science education and have often acquired one level higher of science education than the level at which they are employed as teachers. Thus the conventional qualification for teaching at the secondary school level would be a graduate degree in science together with a year of professional teacher training. The pattern of vocational training for teachers in the natural sciences derives from the intellectual structure of science itself (Ziman, 1980). This type of training has a significant effect on the goals of science education. It fails to provide enough experience in attending to the needs of the many students with different vocational intentions. They reflect unconsciously a greater esteem for abstract theory than for practical techniques or for scientific literacy as part of a common culture. There is a strong possibility that intellectual snobbery can be reinforced by current vocational training. While one is justified in arguing that science teaching should respect the intellectual imperatives of pure science especially for those whose careers are to be in the field of science and technology, it fails to take into consideration the greater mass of the students whose careers are connected with non-scientific employment, yet whose lives are very much shaped and influenced by developments in the field of science and technology.

Another point of interest is that the current nature of degree courses reinforces the practice of teaching single-science disciplines in secondary schools, and often makes teachers proponents of specialisation and fragmentation. Within the university, each science subject is well insulated from each other. Teachers are deprived of a holistic view of science, and what they receive are compartmentalised packages of scientific knowledge and sometimes not all the essential packages. As a result, teachers tend to develop a positive attitude towards the subject(s) they teach and an attitude of disdain or disinterest towards those that they do not teach. These attitudes are either unconsciously or consciously transmitted to the students.

Teachers' interpretation and utilisation of new science curricula are also of importance in the success or failure of science education. Brown & McIntyre (1982) have found that teachers do not always use new ideas in ways they were intended. How teachers make sense of innovative ideas and use them in classrooms are dependent not only on the nature and quality of information and support they are offered, but also on their own ideas about how their subjects should be taught and on the constraints which exist in their day to day work. Studies of the role of teachers in curriculum development document the extent of unwillingness to reorient their teaching and a resistance to the use of innovative ideas as intended. Herron (1971), in interviewing teachers of the BSCS materials, found that, in general, teachers using the materials did not have the same degree of understanding of the nature of science as the designers of the project did. Herron concluded that: "Teachers' perception of new course material...is a problem that lies at the root of resistance to curriculum change" (p.48). According to Bradley, Chesson & Silverleaf (1983), with innovative programmes teachers are being asked to possess a more varied range of professional skills to meet the demands being made by the introduction of new types of courses. Teachers sometimes shy away from innovative programmes or fail to do adequate justice to the aims of such programmes. The failure of innovative programmes is thus due to lack of appropriate staff training and development. This is probably not the fault of the teachers but the designers of new programmes whose responsibility it is to see that teachers get the necessary training.

It has also been found (Shipman, 1974: 47) that teachers tend to inject their own problems and perspective into any particular programme. The consequence is that basic principles behind any project are usually misunderstood and often unconsidered. It is sometimes the narrow interest of teachers which creates the barrier to successful implementation of an innovative curriculum. It appears that teachers 'conserve' personal values and satisfaction in the face of more universalistic expectations because they are trying to cope with work demands which are difficult to understand. Teachers construe giving notes as productive (good for passing exams) and choose to give notes in spite of the innovative doctrine's call to do otherwise. The anticipation of the effects of a particular teaching approach on success at passing exam allows teachers to assess and make choices. The significant point is that these choices tend to preserve the more narrow and satisfying elements of teaching science at the expense of more universalistic expectations of new science programmes.

Earlier in the Chapter I looked at the problem of language and communication mainly in terms of the student and the textbook. There is also the problem of communication between teachers and proponents of innovation and teachers and students. According to Olsen (1983), curriculum innovators often do not understand what teachers are trying to do. As a consequence a gap exists: what one group means to say, the other does not understand. Proponents of innovative programmes attempt to communicate their ideas to teachers using terms which may have little importance in the 'systemic' structure of the teacher's everyday language. The meanings that teachers may attach to terms and ideas derived from the theoretical structure of the innovators' ideas are sometimes at variance with the meanings curriculum designers had in mind. Language derived from a particular brand of cognitive psychology very often leads to personal teacher interpretation. For example, students are often expected to engage in 'problem solving' and 'pattern findings' but Olson (1982: 27) found that teachers had a different understanding when compared with the precise technical meanings in the theoretical language of the planners.

Pattern finding was seen by teachers as finding patterns in things, like patterns in a painting. Problem solving was solving problems like starting a stalled car. What the writers of innovative science programmes often mean are different from teachers' interpretation. There is also communication problem between the teacher and students. Teachers often mean more than they say. For the sake of brevity, time, etc. teachers telescope their teaching into a brief sentence loaded with meaning. Students often have to scramble to find out what the teacher means by what he/she says. Not only what the teacher says is difficult for the student to understand but there is the possibility that the student will arrive at an understanding different from what the teacher means. Problems (Osborne, Freyberg, Tasker & Stead, 1982) arise as a result of different perceptions teachers and pupils have of a learning experience. By failing to explore first the range of concepts already held by students means that the teacher is unlikely to be aware of the meanings students associate with different words.

Finally, most comparative studies have shown activity-based programmes to be equal to or superior to text-based instructions on the variables measured. However, supremacy in outcomes are not consistently found and improvements in learning are frequently not as great as anticipated. Several reasons for this have been identified including the lack of in-service training, money for equipment kits and materials, and support systems to provide needed materials and equipment. But also there are problems at the classroom level - these mainly concern teachers' understanding and intentions. Smith & Sendelbach (1982) found that significant modifications were made to science programmes, not all beneficial. Discussion activities were curtailed. Teachers did not know the rules governing discussion, but they did know that allowing the pupils to talk freely in class undermined their influence. It was also found that teachers placed greater stress upon procedural instructions and little on the development of ideas. Teachers tended to focus on the successful completion of an experiment - doing it properly. They were less concerned with developing a questioning approach - the why activities (see earlier section of this Chapter dealing with the tradition of practical work).

The nature of the problems outlined here indicates that there are inadequacies in the professional training of teachers. The problems are further compounded by teachers' attitude concerning what students need to be taught and how they should be taught. Despite developments in the field of cognitive psychology and application of these to new teaching and learning methods, teachers continue to use 'old fashioned' methods. It has been argued that the persistence of traditional teaching methods is due to teachers' perception of traditional methods, as being superior and/or their lack of experience and therefore confidence in coping with an inquiry approach.

Review and some conclusions

In this Chapter I explored certain features of science education. It was found that much of the 'first generation' science programmes had been designed to meet the needs of the minority who are scientifically inclined or more specifically those who can readily conform to the demands of a syllabus-bound, fact-laden, didactic form of education. For all intents and purposes science education reflects little concern for the individual differences in cognitive styles and personalities. Much of what passes as science education remain an inculcation into the paradigm of the day through standard problems, exemplars, and practical work. This means that science education, to a large extent, is geared to the production of competent normal scientists.

Such an approach has its deficiencies. The whole point of science education is not simply to produce competent puzzle-solvers although this is an important part of science education. If puzzle-solving were the whole point of science, there would be no reason to believe that an uncritical thinker would be a more competent puzzle-solver than one who possessed a talent for critical enquiry. However, it is maintained that science education should go beyond the production of practitioners of science. Science education also needs to be concerned with fostering certain propensities, attitudes and habits of thought, such as critical/independent thinking and creativity because these are desirable over and above their contribution to the successful scientist. Science needs not only competent puzzle-solvers but also people (including puzzle-solvers) with intuition, imagination and creativity as these are essential ingredients of revolutionary science. But even more important, society needs a general public with greater scientific literacy.

Another point raised in this Chapter was the implication of fragmentation and specialisation in school science. The practice of teaching separate science subjects promotes a separate, piece meal view of science in theory and subsequently of nature itself rather than a composite view. Specialisation can lead to greater emphasis on learning of factual and conceptual knowledge, noting that the support for specialisation comes from those who point out that the amount of factual information is accumulating. Advocates of specialisation perceive science education as largely an inculcation of factual information. They fail to recognise that science education is more than knowing facts. It entails understanding principles and the ability to inject new ideas and to scrutinize ideas, facts, and explanations critically. The benefits accrued from such an education extend beyond the narrow fields of science and technology.

The success of any science curriculum is to a large extent dependent upon teachers' professional training, their attitudes towards science education, and their understanding of the nature of science. If a dogmatic inculcation of a particular paradigm is the goal of secondary science education then teachers are well qualified for this function. However, since such a goal has been found to be inadequate, narrow, and restrictive then the type of training that teachers get is inappropriate. Teachers have been found to lack an adequate understanding of the nature of science and their attitudes reflect an endorsement of the intellectual rigours of science. So, in some ways, teachers contribute to the perpetuation of misconceptions about science and to student dissatisfaction with school science.

CHAPTER SIX

NEW DIRECTIONS IN SCIENCE EDUCATION

To review what has been examined so far it can be stated that there are a number of pressing problems confronting society as a whole, and some of these are of particular concern to science educators. At the more general level, there are expressions of growing concern about a wide variety of problems which are considered to be a consequence of uncontrolled scientific and technological developments. More and more voices are being raised against environmental pollution, diminishing non-renewable natural resources, the unimproved plight of the poor, controversial issues about certain types of research, the economic value of some areas of scientific activity and the all pervasive but oppressive and alienating influence of scientific 'objectivity' and 'emotional neutrality' in other spheres of human activity. The nature of scientific and technological developments has much to do with various problems confronting society. *Because* of these problems generated by science and technology and science education, science education must change, to become a *positive* influence. It can help in minimising the environmental and science-related social problems and some of the problems associated with school science by providing a better understanding of the nature and method of science and by establishing a new direction whereby a greater awareness of the importance of ecological balance, of the effect of uncontrolled technological developments, and so forth, can be fostered. However school science's contribution towards the amelioration of the current problems has been less than it might have been because of its own inadequacies.

It has been found that commitment (mostly unconscious) to the 'Methodological Reductionist' interpretation of science and its methodology, and support for a narrow, 'functional' perspective of science education have resulted in the acceptance and reification of the following misconceptions:

(i) that science and the scientist are 'objective', impersonal, neutral, etc.;

(ii) that the process of science is primarily inductive and empirical;

(iii) that growth of science is cumulative;

(iv) that science is value-free;

(v) that science is infallible, true, and certain;

(vi) that the central role of science is to facilitate man's domination of nature;

(vii) that science is capable of providing all the answers as long as one diligently follows the tenets of 'Methodological Reductionism';

(viii) that all scientific phenomena are reducible to the laws of physics; and

(ix) that science education should focus on the acquisition of scientific facts and principles through what appears to be a somewhat rigorous inculcation of the dominant paradigm of the day.

It has also been suggested that teachers not only lack sufficient understanding of the nature of science but are also ill-equipped to do adequate justice to recent, innovative science programmes. Teachers' views of the purpose of science education, and indeed of education in its entirety, have remained largely traditional. That is, science education is seen mainly as being 'functional' and selective. Current school science, because of its inadequacies, is unable to cope with recent shifts in the nature of science, society, and technology and the essential linkages of these factors. It has so far been unable to stem the decline in interest in and dissatisfaction with science. All these signal that a re-examination and revision of the framework upon which understanding of the nature of science is based, are needed.

In this final Chapter I shall outline a possible strategy for change and hope that this may in some way help to minimise the problems inherent in secondary school science, keeping in mind the extreme complexity of the task. It needs to be pointed out that there is no one single viable way of resolving some of the problems confronting science educators; there is no single approach that will meet the perceived needs of all students in all science courses because of differences of opinion amongst advocates of various approaches to curriculum reforms. The initial task is to determine the rationale and goals of science education that may help to eliminate ingrained assumptions about the purpose of science education, increase the level of scientific literacy, foster a greater appreciation of the role of education in science, regain some support for science, increase public confidence in science/technology, and redress the trend away from school science. I shall therefore address myself to

(i) some of the changes that need to be made to the goals of science education;

(ii) changes necessary at the methodological and philosophical levels; and

(iii) the possible role of the science teacher in the design and development of innovative science programmes.

<u>New directions/goals</u>

School science is considered mechanical and cold by many students because it is perceived as being far removed from direct human experiences and as being overly quantitative, factual, mathematical, difficult, and so forth. Much of modern science is seen as dealing with matter under conditions far removed from the human environment and social experiences. The positivistic framework, according to the physicist Weisskopf (1976), has influenced the study of nature not as a totality but as isolated and separable phenomena. This remoteness of scientific knowledge from human interest has been consequential in the failure of school science in communicating its ideas in a manner that matches and emphasises human interaction. In other words, commitment (unconscious or realised) to 'Methodological Reductionism' with its tenets of abstract symbolism, objectivity, neutrality, etc. has tended to prevent science being projected as a human activity.

Furthermore, the current single-discipline oriented science programmes have been overlaid by the weight of formal exercise and formal knowledge to such an extent that relevant application of scientific knowledge to the welfare of man has found little place in the prevailing schemes. Traditional school science can be regarded as a type of elimination contest, a method of separating young science aspirants from the rest of the student population. This is made possible through content-oriented science courses and a teaching method that has remained largely didactic. Dogged rote learning is generously rewarded through tests and examinations that reinforce acquisition of factual knowledge. Unfortunately, the nature of current science education is such that it adversely affects those who cannot conform to a syllabus-bound, fact-laden and overly formal teaching and learning. School science, in general, lacks teaching that fosters the kind of daring involved in making creative and unorthodox intellectual connections - something which is very much a part of revolutionary science. Of course, this does not mean that one should proceed with a complete elimination of formal exercise and formal knowledge from school science. Such traditions of school science should be retained but have a limited role in the new scheme.

To overcome the deficiencies, a change in attitude towards and belief about the purpose of science education is necessary. There has to be a general agreement that the responsibility of high school science is not only to produce future paradigm-bound puzzle-solvers but also individuals with creativity and divergent ways of thinking. Science education also needs to serve those who have no intention of taking up careers in the field of science and technology, because it is strongly felt that every individual should acquire the necessary scientific skills, attitudes and knowledge with which to make sense out of the rapidly changing world. It is recommended that science education should take into consideration the following types of goals:

(i) to help students develop a realistic, non-mythical understanding of the nature and processes of science;

(ii) to provide students with an insight into the interaction of science and technology and in turn into the interaction of these with other aspects of society, for instance, politics, economics, etc.;

(iii) to have students develop a variety of inquiry skills and a realistic feeling of personal competence in the areas of interpreting, responding to, and evaluating their scientific and technological society;

(iv) to make students aware that developments in science and technology can have both beneficial and detrimental effects on society and the environment;

(v) to make students appreciate that many of the earth's resources are finite;

(vi) to help students recognize that moral considerations are involved in decision-making related to science since science is neither autonomous nor value-free;

(vii) to make students aware that citizen participation in science-related policies is desirable;

(viii) to improve student's capacity to learn from experience, criticize one's own work and be receptive to points of view of others; and

(ix) to help students develop some degree of creative skills and divergent ways of thinking.

Although this set of general objectives is by no means exhaustive it provides a general picture of the type of science education so necessary for today's pupils and for future generations. Such goals are equally appropriate for those who become scientists. The great significance of having these or some other set of goals is that it paves the way for developing appropriate mechanisms: courses, etc..

An alternative philosophical/methodological rationale for science 'processes'

It has been argued that commitment to 'Methodological Reductionism' pervades the presently held view of science 'processes'. In the light of criticisms levelled against the tenets of the 'Methodological Reductionist' view of science, it is apparent that the current conception of science 'processes' is inadequate. Failure to take into consideration the epistemological foundation of any science programme, could well mean that later innovations may continue to be based on erroneous and simplistic views of what scientists do and how science progresses. However selecting and adopting a philosophical/ methodological foundation for science education is somewhat problematic. The nature of science is neither simple nor transparent/obvious and endeavours of both philosophers and historians have not yet resulted in a wholly satisfactory analysis of science and its methodology. There is a lack of consensus and continued disagreements between the various schools of thought in the modern philosophy of science. This places the science educator in the position of having to judge the relative merits and probably pedagogic convenience of conflicting interpretations of the nature of science; therefore the qualifications and personal qualities of science educators come into the foreground.

Currently, major science programmes have no explicit philosophical position, but commitment to 'Methodological Reductionist' explanation of the nature and processes of science together with unquestioned beliefs and assumptions about science as part of a common culture is all too evident (Smolicz and Nunan, 1975; Brush, 1976; Cawthron & Rowell, 1978; Finley, 1983). However the inductivist-empiricist framework has been found to offer a misleading and inadequate picture of the relationship between theory and empirical facts, of the role of the experimenter (Scheffler, 1967; Medawar, 1969; Kuhn, 1970; Lakatos, 1970; Popper, 1959, 1983; Finley, 1983), of how science should be taught (Kuhn, 1963; Pippard, 1972; Layton, 1973a; Ziman, 1980), and of science and scientists (Kuhn, 1963; Mackay, 1970; Medawar, 1972; Smolicz & Nunan, 1975; Young, 1977; Cawthron & Rowell, 1978). If, as recent philosophers of science (such as Shapere, Scheffler, Feyerabend, Kuhn, Popper) have suggested, processes as fundamental as observation are dependent upon the conceptual knowledge of the observer, then a modification of the view of scientific enquiry is called for. It has been outlined that science proceeds in light of available conceptual knowledge (see Chapter 3). The conceptual knowledge of researchers determines what constitutes a problem for a particular subject, which hypotheses will be determined, what experiments will be conducted, what data will be sought, how observations will be organised and classified, and what perceptions the observer will select as relevant facts.

From such arguments, it can be seen that science contains a considerable element of deductive process of confirmation/corroboration. The core of the current view is that scientists formulate tentative hypotheses, based on their conceptual knowledge, early in an investigation. The basis of formulation of an hypothesis is a speculative adventure, an imaginative formulation of what might be true - a formulation which possibly goes beyond anything which we have logical or factual authority to believe in (Popper, 1959). In terms of school science, science educators will need to recognize that conceptual knowledge initiates and directs the science 'processes' as well as resulting from them. So instead of requiring the student to make theory-free observations or suggesting that they make a number of observations in the hope of formulating a generalised statement, the following strategy may be more fruitful and meaningful for the student. According to Tasker, Freyberg & Osborne (1982), teachers need to explore first the range of concepts already held by children. Armed with this information teachers would be better placed to devise the teaching strategy rather than the current practice of teaching built on how scientists and curriculum developers logically analyse their own mature concepts. It should not be assumed that prior to formal teaching the learner has no knowledge of a topic (Fensham, 1980; Osborne, 1983).

This assumption is entirely fallacious and indicates the influence of traditional empiricism. According to Popper (1983: 99), traditional empiricism tries to describe the mind with the help of "metaphors, as a tabula rasa - something like a well-wiped blackboard or an unexposed photographic plate - to be engraved by observations. This theory, which I have called 'the bucket theory of the mind', views the mind as a bucket and the senses as funnels through which the bucket can slowly be filled by observations. The sum total of these observations...is 'our knowledge'." Contrary to this empiricist view, it should be realised that students often bring with them, to lessons, meanings for words and concepts of the natural and technological world which are commonly used in science and these meanings may often be different from formal science meanings (Tasker, 1981; Gilbert, Watts & Osborne, 1983; Osborne & Wittrock, 1983).

Armed with some understanding of the student's prior concepts and meanings the teacher can then create a situation, the explanation of which is a central issue in the topic under consideration. The situation, in the form of a simple problem, observation or experiment, should be such that it requires the student to evoke his/her personal view in order to interpret it. The nature and complexity of the student's explanation will be based upon his/her pre-scientific, cultural or social knowledge. This step can be regarded as the initial stage in the teaching of science and is in some way equivalent to the stage of primitive scientific endeavour when scientists investigate natural phenomena using many methods of scientific enquiry. Without the restrictions of an established research tradition or paradigm, scientists feel free to choose their own particular mode of inquiry along their own lines of interest and to explore nature on the basis of prior expectations. Seen in retrospect, this stage appears to be a highly speculative and creative phase in the development of science.

In the context of science teaching, students may hold different viewpoints based upon their current beliefs about the nature of the physical universe, prior experience in other areas, practical considerations, and personal accident. Because this is a crucial phase in the successful teaching and learning of science, teachers should encourage students to formulate hypotheses and perceptions, in ways which make sense to them, rather than forcing them through unfamiliar conceptual boxes. What seems to be desirable at this stage of a pupil's intellectual development is a teaching strategy which enables the pupil to push his divergent mode of thought to the limit and thereby prepare the way for changes in his existing knowledge of science. There is no doubt that requiring students to formulate hypothetical statements is a huge, difficult and fundamentally important problem. To ease the problem somewhat, teachers should be aware of the following:

(i) students bring along with them a wide variety of concepts about the natural and technological world;

(ii) there are often considerable differences between student and teacher perception of a particular scientific event;

(iii) the meanings that students associate with specific scientific terms may be different from the meanings teachers have in mind;

(iv) teachers should not assume that learners have a 'blank mind' to be 'filled' with formal science;

(v) teachers should remember that an unfamiliar language is a less efficient mediator between the learner and knowledge than a familiar one (Claydon, Knight & Rado, 1977: 102); and

(vi) there is a close interaction between cognitive and language development.

According to Piaget (Claydon, Knight & Rado, 1977: 106), the roots of language are in the learner's sensori-motor experiences. On the basis of this the child's natural guide in selecting the linguistic forms is the cognitive development. In other words, as the learner forms concepts he will look for their linguistic expressions. He will ignore what is not of interest to him or what is beyond his cognitive and linguistic abilities.

It needs to be realised that there are limitations to the pupils' mode of thought to cope intellectually with preconceptions of the world. Generally, pupils will not be able to see the kind of subtle order in natural events the scientists can see with the aid of their highly developed and sophisticated abstract-conceptual apparatus. Just as the evolutionary pattern of development in science has its origin in primitive beginnings, so does the student begin with common sense view of the world and require a period of time in which to broaden and deepen his/her understanding of the physical universe - the period of 'assimilation'. In the process of assimilation, according to Piaget (as cited by Bassett, Watts & Nurcombe, 1978: 90), the child relates what he perceives to his existing understandings; new information may be distorted to fit in with these existing understandings.

It may be appropriate at this stage to turn to Piaget's theory of intellectual development as a source of learning strategy. We see that Piaget (Bassett, Watts & Nurcombe, 1978: 92) traces the child's evolving cognitive growth towards maturity by focussing on qualitative changes as the learner passes through a series of maturational stages - the sensori-motor period, pre-operational period, concrete operations period and finally the period of formal operation. These stages are universal and new capacities depend on mastery of the prior stage as new capabilities are incorporated into and integrated with previously existing ones. The transition from one Piagetian stage (Cawthron & Rowell, 1978: 49) to the next is not necessarily sudden and that one stage may still be in operation while the subsequent stage is developing. Each stage is said to develop out of the preceding one and subsumes the latter within a higher structural organisation.

After eliciting from the students their tentative statements about a certain phenomenon or problem, the teacher can help refine and structure these hypothetical statements. It is these statements that will then determine what data are to be collected and how they are to go about collecting the data. After classifying the data, expressions of the information derived from the data can be constructed and checked against the hypothesis. With the teacher initiating and supporting argumentation based upon observations and the methods of investigation, it is possible to develop students' own critical attitude. Failure to recognize the student as a theorist could well lead to the suppression of students' creative skills and could also lead to acceptance of science as an objectively available body of knowledge (Young, 1977).

It is through teacher-guided experimentation and observation that contradictions inherent in the learner's mode of thought can be exposed. The role of the teacher is one of inducing the learner to recognise the difficulties and contradictions implicit in his thinking. Not only do the contradictions need to be convincingly resolved but they must also be understood because failure to do so could lead to a continued student adherence to inadequate and misleading scientific understanding. Osborne (1983) found that students have strongly-held views about a variety of topics in science, from a young age, and these views can remain uninfluenced (or are influenced in unanticipated ways) by science teaching. One possible reason for this predicament is that science teaching often imposes a new view of certain scientific phenomena without first convincing students of inadequacies in their view of nature. Going back to Piaget (Bassett, Watts & Nurcombe, 1978: 90) we can see that this stage of cognitive development entails the process of 'accommodation'. In accommodation, the child alters existing structures to accommodate new facts or new information. Posner, Strike, Hewson & Gertzog (1982) explored the conditions under which students' current concepts come to be replaced by new ones and what features govern the selection of new concepts. They suggested that the following conditions need to be fulfilled before an accommodation is likely to occur:

(i) there must be dissatisfaction with existing conceptions as a result of a student having collected a store of unsolved puzzles or anomalies - this could then lead to a loss of confidence in one's own conceptions;

(ii) the learner must be able to make sense out of the new conception;

(iii) if a new concept is to be accepted by the learner it must appear to be plausible by having the capacity to solve problems which the old conceptions are unable to; and

(iv) a new concept should have the potential to open new areas of inquiry.

According to Posner, Strike, Hewson & Gertzog (1982: 214-5), the features that will influence a student to discard his own ideas and accept new ones, are:

(i) anomalies of the specific failures of a given concept;

(ii) "analogues and metaphors" which can help to give rise to new ideas and make them understandable;

(iii) "epistemological commitments" - explanations that are acceptable to that particular subject and are elegant, concise, pertinent, etc.;

(iv) "metaphysical beliefs and concepts" - beliefs must be orderly, symmetrical and non-random and specific scientific concepts need to have a certain metaphysical quality, i.e. they should encompass beliefs about the ultimate nature of the universe; and

(v) a new concept should appear to have more promise than old concepts.

However, to facilitate a successful transition from a limited or inadequate conception of science of the pre-paradigm stage to a more universal but simplified conception of science, teachers need to bridge the communication gap between the conceptions (Stenhouse, 1979). For the teacher, the problem is two-fold. Firstly, he has to understand the student's own language of communication and perception of the world; and secondly, he must be able to present more universal scientific ideas in a manner that can be easily understood by the student. To bridge the gap, it would be necessary to translate the scientific language into ordinary language of communication or else meanings of scientific terms, ideas, and theories will continue to elude the learner. The teacher/student communication problem has been discussed briefly in

Chapter 5. The stage when a conceptual change becomes necessary is discussed again later in this Chapter.

One common complaint about current science education is that complex concepts of science are being introduced at a time when the average student in the class is not conceptually equipped (see Chapter 5, under the sub-heading, The major goal of science education). As mentioned earlier, a child needs to pass successfully from one Piagetian stage to another and the transition need not be sudden. With this in mind together with the conditions for successful conceptual change suggested by Posner, Strike, Hewson & Gertzog (1982), the following strategy could be incorporated in science education. To facilitate a conceptual change, a learner should begin with common sense views of nature, heavily dependent on immediate, concrete empirical experience. From here one can then proceed to the level of formal operations. But before transition to the level of formal operations is attempted there should be a horizontal extension of experiences at the concrete level of operation through observations and experimentation, that is a consolidation of the process of assimilation and broadening on the linguistic expressions of the learner. It is apparent that scientific ideas cannot be made easier all the time, but they can be introduced in different ways and to different depths so that the learner's understanding is able to grow progressively. Consider for example, the topic: 'acids and bases' in chemistry. How can one initially introduce this topic and develop it vertically through the appropriate Piagetian levels? Firstly, the teacher can explore students own conceptions of acids and bases and elicit from them what they know about this class of chemicals. For many the term 'base' might be a new scientific idea. If such is the case, the term 'base' should not be introduced in isolation. It needs to be linked to students' conceptions of acids and salts. The initial explanation of acids and bases should be based on physical properties (e.g. has a sour taste, etc.) and be linked to vivid, tangible experiences. From here, students could proceed to carry out tests to identify dilute acids and bases, using litmus paper. Examples of a wide variety of acids and bases (including examples from the student's own environment) should be provided for classification into two separate groups of chemicals. The litmus paper test can often be meaningless unless the student has some basic understanding of what indicators are. After several lessons, further exploration can be undertaken - this time looking at the chemical properties e.g., reaction or non-reaction of dilute acids and bases with some metals. With the introduction of the idea of differing strengths of acids and bases, students would soon realise that their existing structures are inadequate for explaining this new idea. To proceed to the ideas of dissociation of acids and bases, and hydrogen ion concentration, may be ill-advised at this early stage. It may be more beneficial to offer a simple but limited explanation of the pH scale and how the pH indicator (paper or solution) can be used not only to distinguish between acids and bases but also help in determining the strengths of different acids and bases.

Further conceptualisation of acids and bases would require thinking at the formal operations level. It may probably mean that the topic has to be left aside for another year during which period other concepts, necessary for a better understanding of acids and bases, are being assimilated and/or accommodated. The acquisition of the following ideas and concepts would facilitate an easier conceptual change: structure of matter, dissociation of liquids, bonding, ions, pH in terms of hydrogen ion concentration, and other pre-requisite ideas. For the next step, individuals will need to utilise the various concepts so far assimilated and/or accommodated; some of these will function to guide the process of conceptual change. Acids and bases can now be explained in terms of protons - proton donor and proton acceptor. For a conceptual reorganization to take place the conditions outlined by Posner, Strike, Hewson & Gertzog (1982) must be fulfilled or else the learner will continue to adhere to previous, limited concepts. The above is a brief outline of a particular example of a scientific idea that can be introduced in different ways and to different depths so that the learner's understanding is able to grow progressively.

Continuing with the general strategy, it is more meaningful to begin with the common sense view of nature because of students' depth of knowledge and experience, and then progress on to more abstract paradigmatic, scientific theories. However it is possible to elicit from the students ideas and views that need not be equated with standard scientific theories in terms of sophistication and abstraction. By allowing students to formulate and propose simplified and limited theoretical ideas, may help in developing a positive attitude towards science and also increase their confidence in their own ability in learning and understanding science. For example, a student may propose that "an acid is a solution that contains more hydrogen than hydroxyl ions and that it willingly donates these excess ions." This is a simplified statement based upon the Bronsted Lowry Theory of acids and bases, and as such it needs to be accepted, expanded and refined gradually.

Following the acquisition of new ideas, students can be involved in a period of developmental activity. This means that the way is open for new ways of observing and experimenting. As Kuhn (1970) pointed out, a new theory gives rise to new problems and different ways of experimenting, perceiving, etc. Observations and experimentations can be formulated as part of the activities in such a manner that they become a highly intellectual undertaking, although this may not be always possible. According to Kuhn, there are many instances when scientists are unable to satisfactorily resolve the puzzles or problems confronting them. When the confrontation becomes serious enough the puzzle may acquire the force of an anomaly and initiate a conceptual change. Such a situation in science is regarded as the period of scientific crises or scientific revolution. The current paradigm of normal science is challenged and threatened by a new theory.

In the context of school science, when a student is unable to resolve certain puzzles, because of inadequacies in his/her current knowledge of science, an anomalous situation would have arisen. There is then a need for a conceptual change. At this juncture, we run into some problems when trying to translate the Kuhnian position on paradigm shift into a strategy for science education. Kuhn (1970) maintains that successive bodies of knowledge, with different paradigms, may become difficult to compare. Since successive stages in science may address different problems, there may be no common measure of their success - they may be incommensurable. He further states that catching on to a new paradigm is possibly a sudden transition to a new way of looking at some aspect of the world. If science educators were to accept the view that each new paradigm defines its own terms, and the breakdown between competing theories is complete, then how can the student be able to compare opposing theories? How can one find out that one theory is better than another? Does the teacher have to wait until the student sees things quite differently, that is, wait for a gestalt switch? Eisner (1983) maintains that because different theories provide different views of the world, it does not follow that there is no way of appraising the value or credibility of a view. This is what he suggests: "First, we can ask what a particular theoretical view enables us to do, that is, we can determine its instrumental utility. Second, we can appraise the consistency of its conclusions with the theoretical premises on which they are based. Third, even if those conclusions are logically consistent with their premises, we may reject the premises. Fourth, we can determine whether there are more economical interpretations of the data than those provided by any particular theoretical view. Fifth, we can judge the degree to which the theory or view is coherent. We can use our rational abilities to appraise the extent to which it hangs together. And sixth, we can assess the view on aesthetic grounds: How elegant is the view? How strongly do we respond to it?" (p.14). It is, therefore, possible to compare two competing theories by utilising the points identified by Eisner. Taking Eisner's explanation of how competing theories can be compared and Posner, Strike,Hewson & Gertzog's proposal on conceptual change, it should be possible to bring about changes in students' conceptualisation of the physical world. However, to bring about a successful transition it is nevertheless necessary to bridge the linguistic gap. This can be achieved, as previously mentioned, by translating both paradigms/concepts into the ordinary language of communication and thereby helping the student compare the two competing paradigms/ concepts and see the differences between them.

The teaching of science as it progresses from the pre-paradigm stage to elementary scientific stage and then to the paradigm-of-the-day stage where abstract theorizing becomes necessary, entails a certain degree of dogmatic initiation. This is unavoidable because students need to be familiar with scientific terms, theories, and principles in order to cope with science at senior high school level. But all teaching at this level need not necessarily be a dogmatic initiation into the dominant paradigm. Science teaching can be liberally sprinkled with controversial scientific issues, non-paradigmatic problems, etc., thereby placing the student in a situation where he has to be critical, has to provide his own point of view, and has to work on problems outside paradigmatic problem-solution guidelines.

Because Kuhn's model of scientific development does seem to fit the scientific enterprise as it exists today more closely than any other model, then innovations in science programmes concerning the conception of science processes can be based on his epistemology. However, this does not mean that Kuhn's position is entirely accurate. It is defective in the sense that it over-emphasises a conformist adherence to rules and puzzle-solving according to a model solution. What is also needed, is a science education modelled upon the tradition of revolutionary science with emphasis on imaginative insight. This requires more attention on the qualitative aspect of scientific work which has been largely ignored.

Kuhn's model of scientific development is also defective in the sense of having a high degree of scientific introversion and disregard of the world outside (Smolicz, 1974; Johnston, 1976). However, Kuhn (1977) concedes that he does "not deny their /that is, the external influences/ existence and admit that no science is insulated from its social milieu" (p.xv). Yet his view of progress in science, upon which the conception of science 'processes' can be based, does not adequately acknowledge the influence of the external social, economic, and cultural factors. As has been pointed out earlier, an important consideration for any modern science programme is the selection of a view of science that accounts for the interaction of science with

with society. The externalists' view of science can be used to provide the framework for the structure of the content of science programmes.

A wider perspective for science content

The present structuring of the content of science programmes is considered to be narrow because of the tendency to avoid acknowledging the interaction of science with society. Today, the social environment of science has been transformed just as science itself has grown from "little" science to "big" science (Price, 1963). There are now increasing social and industrial implications of science. Therefore, it is not only scientists who need a better understanding of the part played by science and technology in society (Young, 1974). It is also desirable that every individual be able to evaluate the implications of science and technology because (i) if science is to progress through researches requiring a public investment and public confidence, then science is a public domain with public responsibilities, and (ii) the social and other consequences are no longer the preserve of scientists considering the general social implications of scientific and technological developments. To suggest a socio-humanistic basis for the content of science curricula does not mean that curriculum reforms should be designed to cope with the complex machinery of the twentieth century. What is required is the type of science education that will increase public awareness of the impact and consequences of scientific and technological developments, that will provide some working knowledge of science, and that which will increase public confidence in questioning and understanding the activities of the scientific community (Bibby, 1974). According to Holton (1976), "whether... [the students] will become scientists or not it is essential... [they] have a chance to see the full vision of science and thereby be protected from narrow blinkers or naive euphoria just as much as from the false and hostile ideas about science and scientists which have been spreading in the last three decades in industrialized countries particularly" (p.322).

This thesis maintains that school science could well adopt a Kuhnian position on the conception of science 'processes' and the externalist view on the structure of scientific content. Both views are necessary for a better understanding of the nature of science and of the relationship of science with other institutions and other fields of knowledge. For a socio-humanistically oriented content, one strategy envisaged is the fuller development of selected topics in science with the object of illuminating the nature of the inter-relationship between science, technology, and society. Each topic can be made multi-disciplinary in its approach by combining the tools of a range of disciplines: history, philosophy, economics, and politics. For example, teaching of industrial processes, besides involving the understanding of chemical principles and reactions could also be related to:

(i) the effects of the industrial products on society;

(ii) the study of the people behind the processes who initially proposed different processing methods;

(iii) possible environmental effects of such industries;

(iv) the economic implications, for example, the extent of the contribution of the industry to the country's economy;

(v) the study of the moral issues, if any, and so forth.

Such a multi-disciplinary approach to the teaching of science has a powerful educational rationale.For instance, many of the problems of the contemporary world and its complex society are multi-disciplinary, yet science education has remained narrow and specialised. In order to express an informed opinion on such matters as pollution, for example, future citizens need to be able to draw on information from various subject sources (Spenser, 1978). For school science to approximate more closely to science as it is practised by professional scientists, a multi-disciplinary approach is needed.

It is also maintained (Speigel-Rösing, 1977) that if science is studied from a socio-humanistic vantage point it opens up three important broader perspectives. First, the image of the scientist and scientific process is subjectivized. Second, there is a shift in investigation away from preconceived concepts towards studies that start from the concepts as perceived by the student. And third, it may lead away from a mechanistic approach to school science. Revealing the other side of the scientist - dogmatic, resisting innovation, fighting new ideas, and stubbornly clinging to old ones - may help in demythologizing the image of scientists that many teachers and students hold. By focusing on the subjective side of science, i.e. how the process of science is affected by preconceptions, emotional hang-ups, stresses, and frustrations the 'story-book image' of scientists can be balanced. If the subjective side of scientific activity is given equal place in school science, it could result in teachers accepting the subjective side of the learner, that is, how his/her emotions, preconceptions, resistance to new ideas as compared to the student's value systems, affect the student in his struggle to grasp concepts and processes of science. In addition, it is believed (Novick & Sutman, 1973; Holton, 1976; Randall, 1976; Biggins, 1977; Aikenhead, 1979 and Bagnall, 1979) that a socio-humanistic orientation in school science may help to motivate the learner, develop a positive attitude towards science and also help in curbing the qualitative and quantitative decline of students selecting science subjects at the senior high school level. According to Layton (1972, 1973a) the applications and social interactions of science should be adopted in science programmes for the following reasons. It is asserted that through acquaintance with scientific ideas applied in situations which are meaningful and relevant to students, that most of them can best approach the understanding of abstract ideas and also utilise scientific ideas in the solution of personal and societal problems.

It may be argued that a more liberal approach to science education could result in a trivialisation of science with the attendant dangers of disturbing the supply of competent scientists and/or paradigm-bound scientists. To be weighed against this is the fact that many pupils are not being attracted to science because it is presented too factually and too rigidly. Furthermore, it is claimed (Young, 1976; Spenser, 1978) that the current specialised education in science has given rise to a new generation of individuals who are wholly ignorant of other ways of knowing and the relationship between science and other subjects. Those who undertake separate sciences are often unable to utilise and integrate these separate forms of knowledge. An integrated approach allows students to be exposed to a more comprehensive view of science. This gives them a better grasp of the whole picture of science and may enable them to grapple with the decisions that society needs to make on the applications of science to human welfare (Gregory, 1982). Undoubtedly there is a need for specialists but at the same time there is a growing need for generalists.

Another point of interest is that a multi-disciplinary orientation opens the way for the teaching of controversial issues. The room for discussion of alternative viewpoints of science-related phenomena is relatively limited in traditional science courses. The situation is somewhat different when controversial issues are involved. The choice of issues on which to focus attention and selection of teaching materials to illustrate particular points are both matters which allow the teacher and the student to hold different viewpoints. Such a situation can help to promote the student's individuality of thought and also help in creating greater awareness of the science/society interactions. One of the possible problems that might be confronted is that teachers may try to avoid controversial issues particularly where the political and educational climate are more pronounced (McConnell, 1982). Yet it is hoped that teachers may soon come around to accepting the place of controversial issues in science education.

The role of the teacher in curriculum innovation

It has often been pointed out (e.g., Ambrogi, 1981) that a possible barrier to the success of any new science programme is the resistance shown by teachers to innovative reforms. Ahlgren & Walberg (1973) and Eggleston (1977) noted that the failure of curriculum reforms to achieve their potential may be due to teachers' lack of confidence and familiarity with new ideas. Teachers are generally, favourably disposed towards traditional curricula and, therefore, they are either unwilling to change to a new programme, or they adapt the new programme according to the intentions and teaching styles of traditional science. Olson (1982) found that teachers do not always use ideas in ways that were intended. How teachers make sense of innovative ideas and use them in the classrooms depend not only on the nature and quality of the information and support they are offered as outsiders, but also on their own ideas about how their subjects should be taught and also on the constraints which exist in their day to day work. It is thus necessary for curriculum writers to bear in mind the practical, linguistic and philosophical considerations generally associated with science teachers. Furthermore, for the success of any innovative programme, it is recommended that teachers be actively involved in the deliberations so as to ensure that they become familiar with the intentions and goals of any such programmes. Teacher involvement can also help motivate teachers to want to use the new materials. By working on the design and development of modular units of new programmes they can have the opportunity to acquire first-hand experience with a wide spectrum of educational problems: defining objectives, outline of teaching and learning strategies, design of materials, preparation of tests, trialling and evaluation.

Because this thesis recommends the replacement of current assumptions/beliefs about science with the philosophical/methodological tenets of modern philosophy of science, it would be extremely unrealistic to expect teachers to readily accept ideas that contradict their current beliefs and practices. Until science teachers get a better grounding in the social studies, history, and philosophy of science changes in science education may be slow and frustrating.

Review of Chapter

It is apparent that science education has a strong negative component for a wide range of reasons. It reflects a commitment to some of the tenets of 'Methodological Reductionism' and an acceptance of misconstrued beliefs about science - beliefs that have become so ingrained that they have rarely been questioned or examined. Such a framework has contributed to misunderstandings about science and scientists. It has also, in part, failed to deal sufficiently with the role of science in the making of human culture and with the impact of scientific and technological developments on society. Time-honoured goals are becoming increasingly difficult to justify, either in terms of the nature of science or in terms of their value for social understanding. This thesis has pointed out the need for rethinking and redefining the goals of science education. New directions concerning the purpose of education in science should be accompanied by a corresponding change in the philosophical/methodological underpinnings based on recent developments in the philosophy of science. Secondly, it has been suggested that a more socio-humanistic approach in the organisation of the content of science programmes should be adopted. While this thesis favours the incorporation of ethical, societal and other relevant issues into new science programmes, it nevertheless recognizes that there may be difficulties in constructing, implementing and consolidating such programmes. Compton (1983) found that teachers seemed unable to effectively incorporate the above mentioned issues into conventional science education. The reasons provided were: overcrowded reading lists, time constraints, lack of facts surrounding controversial issues, lack of adequate knowledge among teachers and the scarcity of reliable, suitable background material. Compton's study reveals some of the practical problems associated with curriculum development and is also a timely reminder that new ideas should not be incorporated into existing programmes but rather a whole new programme be developed. Finally, it has been pointed out that any reforms in school science, to be effective, will require not only a re-assessment of the appropriateness of current teacher education (because innovations in science education by themselves are no guarantee for the success of innovative programmes) but also teacher involvement in curriculum development.

It is hoped that a change in the philosophical/ methodological framework, together with the adoption of a socio-humanistic orientation, may retain for school science its declining interest and at the same time help to reduce common misconceptions about science and the scientist.

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