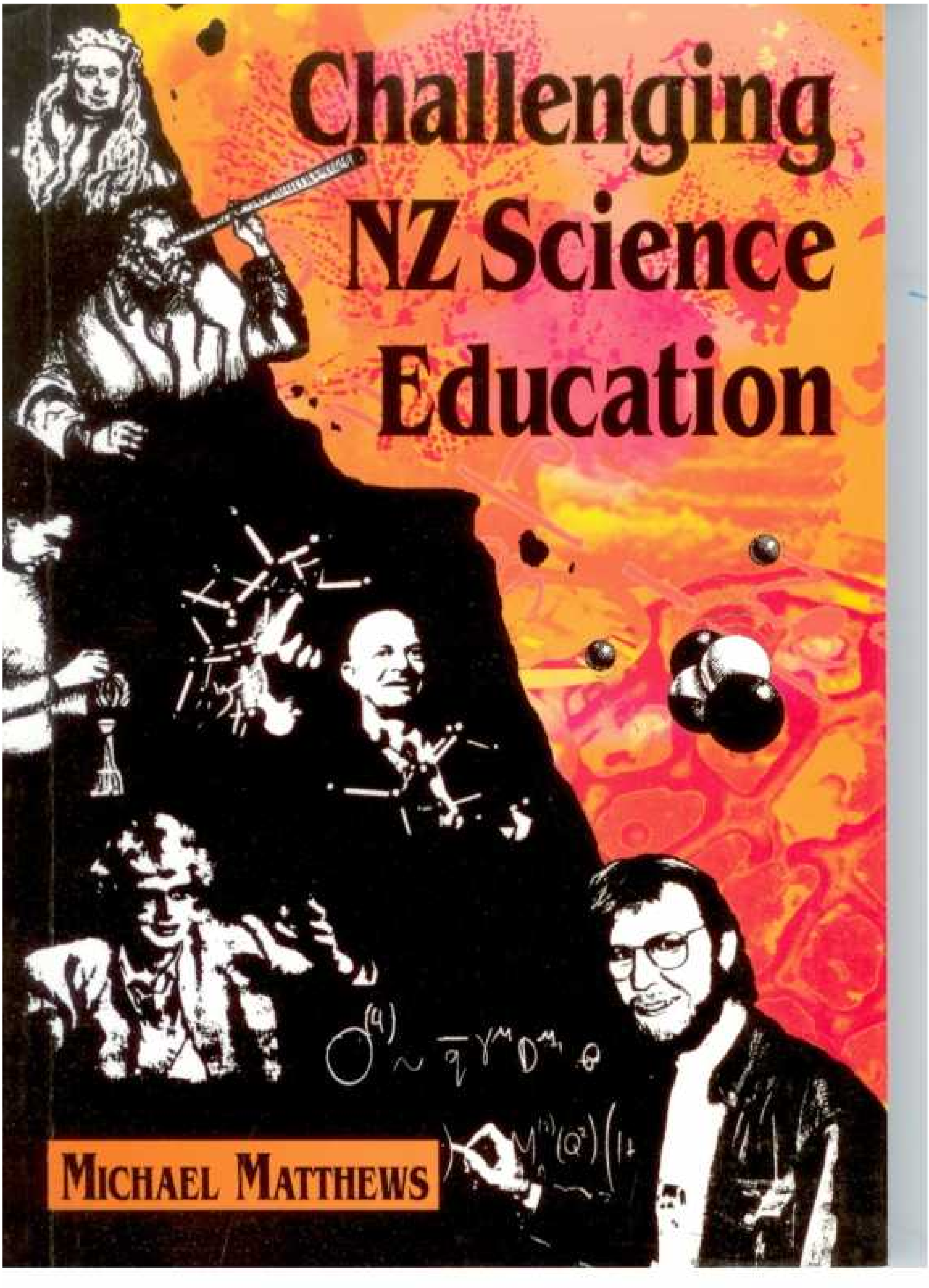
Challenging NZ Science Education
MICHAEL MATTHEWS

CHALLENGING NEW ZEALAND

SCIENCE EDUCATION

Michael R. Matthews

To the University of Auckland

in appreciation of my period as Foundation Professor of Science Education (1*992-93)*

The concept of 'truth' as something dependent upon facts largely outside human control has been one of the ways in which philosophy hitherto has inculcated [a] necessary element of humility. When this check upon pride is removed, a further step is taken on the road towards a certain kind of madness – the intoxication of power ... to which modern men, whether philosophers or not, are prone. I am persuaded that this intoxication is the greatest danger of our time, and that any philosophy which, however unintentionally, contributes to it is increasing the danger of vast social disaster.

(Bertrand Russell, 1946, p. 781)

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I am grateful to the University of Auckland where I spent two enjoyable and productive years (1992-93) as Foundation Professor of Science Education. The university provided the conditions for research, scholarship, and travel that enabled this book to be written. Sir Colin Maiden, the former Vice-Chancellor, was instrumental in the establishment of the chair, and in providing generous support for the university's venture into science education studies. Professor Jim Marshall, Dean of Education, at Auckland, provided valued encouragement and support for my professional and public activities. I was also pleased to receive the support of members of the university's Education Department, Philosophy Department and Faculty of Science.

My graduate students at Auckland were an inspiration. They were a major reason for writing this book as, in my estimation, their studies both in science and in education were truncated. They were bright and energetic students, but their education had left them in ignorance of the history and philosophy of the subject matter they were teaching. I thought this was a serious limitation, and sought to redress it in my teaching and writing.

This book had its origins in a kind invitation from Mr Michael Irwin, on behalf of the Education Forum, to write a monograph on the 1993 New Zealand Science Curriculum to be published in their Occasional Series. He was patient with the long delay in completing the project and, when its length had far exceeded its original purpose, he was supportive of my efforts to find an alternative publisher.

I am grateful to Mr Murray Gatenby of Dunmore Press who has been cooperative and enthusiastic at all stages of the book's production.

Finally, as with most of my published work, I owe a great debt to my wife, Julie House, for her encouragement in this project, for discussion of many of the issues in the book, and for her painstaking criticism, copy-editing and proof-reading of the manuscript. Her labours have made the book considerably more focused and readable than it otherwise would have been.

PREFACE

Toward the end of my two-year period as Foundation Professor of Science Education at the University of Auckland a public debate erupted over the then just released *Science in the New Zealand Curriculum* document (Ministry of Education, 1993). This debate was carried on in all major newspapers in the country, some radio programmes and in a television interview with the Minister of Education. The debate was contributed to by university staff, school teachers, principals, Ministry officials and others. A number of large public meetings were held in Auckland, with over 200 people attending each one. The debate was about the influence of the philosophical and psychological doctrine of Constructivism on New Zealand science education, and more specifically on the National Curriculum document.

The debate was sparked by two articles in Auckland's *New Zealand Herald* newspaper, written by school teachers and complaining first about the introduction of Achievement Based Assessment (ABA), and second, about the 'Dumbing Down of the Curriculum'. The debate went national when I supported the teachers by contributing an article titled 'Curriculum Reform Degrades Sciences' (*NZH*, 26 August 1993). This article was reproduced in Christchurch's *The Press* (27 September), and Wellington's *The Dominion* (12 October). Within a few months of writing the *New Zealand Herald* article, I, for pressing family reasons, had to return to Australia.

It was, and still is, my belief that the issues raised in the science curriculum debate have a relevance far beyond the science classroom. They touch upon a number of fundamental educational principles, and they ultimately impinge on the health of New Zealand society and culture. This book is an attempt to address in a more systematic way the issues that the 1993 debate opened up, and to place those issues in the wider context of debate about the purposes and achievements of New Zealand schooling.

It is fitting in the Preface to this work to reproduce my original *New Zealand Herald* article. The matters raised there will be amplified and defended in the chapters of this work. The article was as follows (with one sentence containing a factual error removed):

> The 'New Zealand Herald' has done a valuable service to the country in publishing the recent articles of Martin Hanson (10 August) and Max Thomson (18 August) on the sorry state of New Zealand science education 'reforms' and the associated changes to school assessment procedures. Hanson and Thomson are right in suggesting that the country is being led into an educational and scientific abyss.
>
> However neither author has identified the doctrinal engine powering the supposed reforms: this is the theory of Constructivism which has been enthusiastically embraced by the official science education establishment in New Zealand. The country is small and thus, unfortunately, only a few key people need convert to a loony doctrine for it to have national influence.
>
> These are exceedingly contentious claims. Not just contentious but many, myself included, would say down-right silly. The mystery is that there seems to have been no criticism of officialdom's wrapping of itself, and New Zealand's science education, in this Constructivist cloak.
>
> The Draft Forms 1-5 Science Syllabus was explicitly based on Constructivist principles. So also is the 1993 Science in the National Curriculum statement. The refrain 'children construct their own knowledge' is repeated mantra-like in these documents. But like most mantras the meaning of the refrain is never examined or defended.

Science in the National Curriculum identifies scientific thinking as: being curious, being creative, having hunches, clarifying ideas and feelings, thinking about your own thinking. All of these traits are laudable, but they are not uniquely scientific. The national curriculum document holds that scientific thinking is anything but knowing science, anything but mastering the special conceptual tools of science.

The same document lists a number of possible learning experiences that are supposed to develop the above version of scientific thinking. These include asking questions about the observed changes during the cooking of pikelets, clarifying ideas on an environmental issue, clarifying ideas about what an animal is, guessing the reason for the distribution of crabs on a rocky shore.

This is scientific thinking made easy, it is scientific thinking without the hard work of conceptual mastery.

One fears for students subjected to this regime. The only opportunity most of them will have to be introduced to the hard-won, culturally significant, world of scientific thought and its disciplines will have been squandered. Scientific thinking is so degraded in the official documents that anything counts as science. Unfortunately for New Zealand students, most of the world, including the best research institutes, do not share this delusion.

Along with this degrading of the subject matter of science, or 'dumbing of the curriculum' as Thomson and Hanson call it, goes a degrading of the profession of teaching. Constructivism fundamentally asserts that knowledge has to be individually constructed, the transmission of knowledge is in principle ruled out.

The Draft Forms 1-5 Syllabus devotes one page to 'the role of the teacher'. Included in its ten-part characterisation of the teacher's role are: ensuring equity for all students, creating a friendly learning environment, listening to students, ensuring students communicate, challenging sensitively the ideas of students and providing resources. A teacher's role is to do everything but teach. Instead of teachers we now have facilitators.

This democratising of the teaching profession might give many a warm feeling, but soon the economic penny will drop: if teachers are just facilitators, then why spend money ensuring they have a science degree, and why pay them high salaries when lots of good but untrained people could equally listen, encourage, support, provide, and challenge students.

What replaces truth and knowledge in constructivist wonderland is 'making sense'. The draft syllabus says that 'Science is about people exploring and investigating their biological, physical, and technical worlds, and making sense of them in logical and creative ways'.

The curriculum opens with a restatement of this sensism doctrine. 'Sensism' appears in nearly all Ministry documents relating to science education.

I believe this is a fundamentally erroneous and dangerous conception of the nature and goals of science: science does not strive to make sense of the world, it strives to find out the truth about the world. These truths when found, normally do not make obvious sense; rather they require the overturn and reconstitution of common sense. As many people have observed, if it makes sense it is probably not scientific.

Most scientific advances have entailed commitment to propositions that literally defied sense – Copernicus's rotating earth, Galileo's point masses and colourless bodies, Newton's inertial systems that

> in principle cannot be experienced, Darwin's gradualist evolutionary assumptions so at odds with the fossil record, Einstein's mass-energy equivalence etc.
>
> Constructivist and relativist ideas have unhappy consequences for culture and social life that are seldom examined. It is notorious that people have for centuries thought that the grossest injustices, and the greatest evils, have all made sense.
>
> The subjection of women to men has, and still does, make perfectly good sense to millions of people and to scores of societies; explaining illness in terms of possession by evil spirits makes perfectly good sense to countless millions; the intellectual inferiority of particular races is perfectly sensible to millions of people including some of the most advanced thinkers. It is clear that the appeal to sense is not going to be sufficient to refute such views; but the appeal to truth which is independent of human desires or power, may be able to overturn such opinions.
>
> Science, and science education, can play a powerful role in the general improvement of culture. But it can only do this if it is seen as seeking the truth about the world, and as being partially successful in its efforts. It can play its much-needed role if it inculcates an attitude of humility before the world: The world judges our claims to knowledge of it, we cannot just construct whatever suits our fancy, our interests, or our culture, and call it knowledge.

The view of science education I argue for, can, in its essentials, be seen in a textbook for science teachers written over sixty years ago. The author F.M. Westaway writes that a successful science teacher is one who:

> ... knows [his/her] own subject ... is widely read in other branches of science ... knows how to teach ... is able to express [him/her self] lucidly ... is skilful in manipulation ... is a logician ... is something of a philosopher ... is so far an historian that [he/she] can sit down with a crowd of [students] and talk to them about the personal equations, the lives, and the work of such geniuses as Galileo, Newton, Faraday and Darwin. More than all this, [he/she] is an enthusiast, full of faith in [his/her] own particular work.
>
> (Westaway, 1929, p. 3)

This is a nice sketch of a liberal, realist and contextural approach to the teaching of science, and of education more generally. If universities, and colleges of education, produced an abundance of such science teachers, New Zealand's science problems would be greatly diminished. The thrust of this book will be to show that the training institutions are not even trying to produce such teachers; and that constructivism, the official ideology, belittles, or at best ignores, such qualities.

In New Zealand, and elsewhere, the liberal approach to education advocated in this book is under threat from elements of the Left and the Right. Old-style Marxists passionately advocated education, and the importance of understanding the natural and social worlds. Education was a means of liberation for the working class. Champions of labour placed a particular emphasis on liberal scientific education. Thomas Huxley in his influential address, 'A Liberal Education; and Where to Find it' (Huxley, 1868), given at the opening of the South London Working Man's College, focused attention on the importance of science to education, and ridiculed contemporary curricula that excluded science, saying that 'the best of our schools and the most complete of our university trainings give but a narrow, one-sided, and essentially illiberal education – while the worst give what is really next to no education at all' (in Bibby, 1971, p. 96). J.D.

Bernal, the Marxist biologist and professor of Birbeck College, followed this line in the 1930s. In one of his essays, 'Science Teaching in General Education', he said: 'The history of science must become a vital part of science teaching, and on the other hand, the understanding of science and of its social importance must enter into all historical courses' (Bernal, 1939/1949, p. 138). Huxley and Bernal, in their praise of science, expressed the long-held, orthodox, left-wing view. However, in the last two decades, this view has significantly changed. Many academic leftists, have become hostile critics of science. This is especially so among sociologists of science, postmodernists of all varieties, certain feminists and cultural constructivists. An excellent recent book on this phenomena has observed that:

> Most surprisingly, there is open hostility toward the *actual content* of scientific knowledge and toward the assumption, which one might have supposed universal among educated people, that scientific knowledge is reasonably reliable and rests on a sound methodology.
>
> (Gross and Levitt, 1994, p. 2)

The conservative right has always had a deep suspicion of science, fearing its effect on religious allegiance and distrusting its essentially democratic values. At the present time, their attack on science education is manifest in vocationalism. Science is tolerated provided it is confined to narrow utilitarian concerns, to the preparation for technical work. Grasping the larger picture of science, and achieving the deeper sense of science literacy as advocated by Huxley and Bernal, are both rejected by vocationalists (as they also were for decades in the U.S.S.R.).

The academic left and the conservative right have joined hands in the current attack upon liberal approaches to science. In New Zealand constructivism's undermining of scientific knowledge claims, its view that there are many equally valid sciences, its insistence that knowledge cannot be transferred, its disregard for the history of science, and its discounting of subject matter competence on the part of teachers – all put it at odds with the classic liberal approach to the teaching of science.

This book will attempt to defend a liberal, rationalist approach, to science pedagogy against its detractors from both the soft left and the conservative right. It proposes a liberal theory of education and pedagogy, *not* a liberal theory of schooling. The former is a normative theory about what *should* happen in schools; the latter, as with all theories of schooling, are factual or social scientific, theories that attempt to understand and explain schools as elements in the reproduction of society. My views on theories of schooling are contained in an early book – *The Marxist Theory of Schooling: A Study of Epistemology and Education* (Brighton: Harvester Press, 1980). My view is that radical education requires traditional, but non-authoritarian, discipline-based pedagogy. But that is a complex and different question from the one addressed in this book. The Harvester book also outlines the realist and historical approach to epistemology that this present book embodies.

The liberal approach to science teaching attempts to teach the content of science (facts, concepts, definitions, laws, formulae, technique and methodology) and also an appreciation and knowledge of science as an important component of our intellectual history and cultural world. The liberal tries to flesh out the picture of science frequently portrayed in technical or professional science education. There science was commonly divorced from its interesting and engaging history, from its interactive impact on culture, religion and worldviews, and from contemporary social and personal concerns. At best this professional tradition presented the skeleton of science. I will also endeavour to show that the constructivist reaction to this tradition is largely mistaken.

This book is critical of aspects of constructivism. as adopted in Waikato University's SMER Centre. The SMER Centre has obviously done a great deal of good for New Zealand science education. I will argue that it has also done harm. In brief, my criticism is that what is good in constructivism has long been known in the liberal tradition of education, and that what is novel in constructivism is misguided and dangerous to both education and society. There are positive aspects of constructivist pedagogy, and a different kind of book would give more attention to them and to the positive contributions of the SMER Centre. But these aspects have received more than their fair share of coverage in New Zealand and elsewhere. I wish to focus on the less aired weaknesses of constructivism and its dubious educational implications.

Readers interested in the approach to science education that I advocate in the final two chapters, are invited to consult my 1994 Routledge book – *Science Teaching: The Role of History and Philosophy of Science*. Also informative are the contributions to my edited book – *History, Philosophy and Science Teaching: Selected Readings* (New York: Teachers College Press, 1991) – and the History and Philosophy of Science volume in the *Science Education Handbook* (Tobin, K. and Fraser, B. eds., Dordrecht: Kluwer Academic Publishers, 1996). See also contributions to the journal *Science & Education*, which is devoted to 'Contributions from the History, Philosophy and Sociology of Science and Mathematics' to science and mathematics education.

Beverley Bell, the director of the SMER Centre, said of herself in an early publication that 'My promotion of the constructivist view of learning and of the curriculum is well known, but I hope my ideas evolve and change too ... To that end I look forward to a lively debate' (Bell, 1986, p. 9). This book might be seen as taking up her challenge to a lively debate about the merits of constructivism. She also quoted Clarence Beeby, the former Director-General of the New Zealand Education Department as saying that 'our research will have been successful if subsequent generations view our findings as naive'. I will argue that, on this criterion, Waikato research has indeed been successful.

Paul Cobb, a U.S. mathematics educator and constructivist, invited me to contribute a critical article to a special issue of a journal he edited on constructivism. On receiving my article he wrote saying that:

> Given that I still work within constructivism, there are significant differences in our positions. This was obviously what I had hoped for when I invited you to participate. Like you, I am worried that constructivism is becoming accepted uncritically as the truth. Clearly, if it is to be of value, it must involve more than the repetition of tired slogans and cliches. In my view, constructive criticisms of the type you make are desperately needed in that they might help raise the level of discourse by inducing people to reflect on some of their basic assumptions.

It is in this spirit that I write this book. I hope that my arguments do encourage people in the education establishment to reflect on some of their basic assumptions, and perhaps change a few. The issues are of fundamental importance.

CHAPTER 1

THE CULTURAL IMPORTANCE OF SCIENCE EDUCATION

A healthy and successful science education is important for all but the most sheltered and isolated societies. Scientific knowledge underpins modern technologies which enable all of us to survive and which can enhance or threaten the quality of our lives. A general understanding and appreciation of science is essential for all citizens. Scientific competence is vital for the future of scientific, medical, industrial and technical work and research in New Zealand. It is important to enable citizens to understand, appreciate and make informed decisions about the technological world in which they live, with its radios, telephones, TVs, motor cars, microwave ovens, videos, machines, appliances and so on. Without a good science education citizens become ill-informed spectators in their technological and natural worlds. All of this is recognised in the New Zealand science curriculum which says that ‘Our dependence on science and technology demands a high level of scientific literacy for all New Zealanders and requires a comprehensive science education for all students, as well as for those who will have careers in science and technology’ (Ministry of Education 1993, p. 7).

Scientific Illiteracy

A 1991 Ministry of Research, Science and Technology study revealed how little New Zealanders knew and cared about science. The study of 1,012 representative adults showed that:

- Fully 90 per cent were scientifically illiterate, having less than a minimum understanding of the processes, terms and social impact of science.
- Only 13 per cent were even attentive or interested in science, with an even smaller percentage of women in the sample being interested.
- Only 3 per cent were both literate and interested; that is most of the 10 per cent who were scientifically literate, were not interested in science!
- Overall there was a negative attitude to science.

(MORST 1991, p. 4).

A 1992 MORST study showed that in 1990 New Zealand universities had three times the number of Arts and Commerce graduates (5,500) as Science and Engineering graduates (1,800); of nine OECD countries, New Zealand had one of the highest concentrations of lawyers and accountants and the lowest concentration of engineers, and the proportion of school students taking Sixth Form science subjects had remained low for years.

These figures are alarming. They indicate the dimension of the educational task ahead of the country, a task for which the new science curriculum will be important.

It is widely recognised that there is a crisis in Western science education. Levels of science literacy are disturbingly low. This is anomalous because science is one of the greatest achievements of human culture. It has a wonderfully interesting and complex past, it has revealed an enormous amount about ourselves and the world in which we live, it has directly and indirectly transformed the social and natural worlds, and the human and environmental problems requiring scientific understanding are pressing – yet, disturbingly, students and teachers are deserting science.

This flight from the science classroom by both teachers and students has been depressingly well documented. In the U.S. in the mid-1980s it was estimated that each year 600 science graduates entered the teaching profession whilst 8,000 left it (Mayer, 1987; Darling-Hammond and Hudson 1990). In 1986, 7,100 U.S. high schools had no course in physics, and 4,200 had no course in chemistry (Mayer, 1987). In 1990 only four states required the three years of basic science recommended by the sobering 1983 report *A Nation at Risk*, the rest allowed high school graduation with only two years science (Beardsley, 1992, p. 80). Irrespective of years required, 70 per cent of all school students drop science at the first available opportunity – which is one reason why in 1986 less than one in five high school graduates had studied any physics. In 1991 the Carnegie Commission on Science, Technology and government warned that the failings of science education were so great that they posed a 'chronic and serious threat to our nation's future' (Beardsley, 1992, p. 79).

In the U.K. recent reports of the National Commission on Education and the Royal Society have both documented similar trends. One commentator has said that 'wherever you look, students are turning away from science. ... Those that do go to university are often of a frighteningly low calibre' (Bown, 1993, p. 12).

The widespread rejection of the Enlightenment project – to understand the world and to thereby improve the human condition, and the rise of anti-science in the West, make the improvement of science teaching an imperative.

The Cultural Significance of Science

Science education is important not just for instrumental reasons – having more engineers, mechanics and nurses. It also has a vital part to play in the understanding and development of culture, and in people's deep-rooted understanding of their place in the wider scheme of things. From the Scientific Revolution of the seventeenth century to the present, science has been a dominant influence in the development of world views, of philosophy, of social science, of large parts of literature and poetry, and even of religious understanding.[1] It is a truism that we live in a scientific age. In order to understand this age – its achievements and limitations – we need to understand something of science. The well known history of conflict between science and religion in the Christian tradition – the Galileo trial, the Darwinian controversy, current population and genetic engineering debates, and so on – indicates that science impinges upon world views, values and personal ideologies.[2] And it is not just the Christian tradition for which this is true. Islam and Eastern religions have all had to make accommodations to, or resist, scientific developments.[3]

This 'world-view' dimension of science is apparent whenever Western science is taught in cultures that do not share Western philosophical traditions. This has given rise to widespread and heated debates about multicultural science education,[4] and in New Zealand to debate about appropriate science education for Maori and Pacific Islander communities. These debates are only in part about pedagogical issues – that is, how best to teach science to Maori and Pacific Island children – they are also about philosophical issues bearing upon *what* kind of science to teach – Western or traditional.

Science affects styles of thinking and reasoning in society. For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instils a concern for evidence, and for having ideas judged not by personal or social interest, but by how the world is – science characteristically separates the ball from the player, the message from the messenger. It contributes to a sense of ‘Cosmic Piety’, as Bertrand Russell called it. These values are under attack both inside and outside universities. We have centuries of evidence, including the twentieth century, that natural thinking is neither rational nor scientific. Scientific thinking has to be carefully cultivated and nurtured. Pseudoscientific and irrational world views have a long history and a seductive appeal.

In the West, antiscience is on the rise.[5] A study at one Canadian university found that a majority of students believed in astrology, extrasensory perception, and reincarnation; while another estimated that 11 per cent of U.S. citizens claim to have seen a ghost (Cromer 1993, p. 34). Surveys conducted over a three year period at the University of Texas revealed that 60 per cent of students thought that some people could predict the future by psychic powers, 35 per cent believed in Black Magic, and the same percentage believed in ghosts; while another survey of U.S. biology teachers estimated that 35 per cent believe that psychic powers can be used to read other people’s minds, 30 per cent reject the theory of evolution, and 20 per cent believe in ghosts (Martin, 1994, p.359). A recent survey by the Australian Institute of Biology of 4,225 first-year biology students from 17 universities in all States showed that one in eight (12 per cent) believed that ‘God created man pretty much in his present form at one time within the last 10,000 years’. Newspaper astrology columns are read by far more people than science columns. Old-fashioned chemistry sets are no longer even marketed, while tarot cards and crystals are available on almost every street corner.

At its best, science in the Enlightenment tradition has been a bulwark against superstition and self-centred interpretations of the world – the historically long-standing and culturally wide-spread tendency to interpret the world in terms of personal and group interests. When the objectivity and rationality of science are eroded, as they are in most postmodernist and constructivist writing, and in all fundamentalist religions, then the power of science to counteract narcissistic personal and ideological tendencies is diminished. J.D. Bernal long-ago illustrated how the rise of Nazism was abetted by irrationalist movements in Germany (Bernal, 1946, p.3). Gerald Holton, a Harvard physicist and historian who for forty years has been writing on the interaction of science and culture, observed that:

> ... history has shown repeatedly that a disaffection with science and its view of the world can turn into a rage that links up with far more sinister movements ... the record from Ancient Greece to Fascist Germany and Stalin’s USSR to our day shows that movements to delegitimate conventional science are ever present and ready to put themselves at the service of other forces that wish to bend the course of civilisation their way – for example by the glorification of populism, folk belief, and violence.
>
> (Holton, 1993, pp. 148, 184)

Two writers in a book on anti-science and contemporary leftist academic movements, observed that:

> The danger, for the moment at least, is not to science itself. What *is* threatened is the capability of the larger culture, which embraces the mass media as well as the more serious processes of education, to interact fruitfully with the sciences, to draw insight from the scientific advances, and, above all, to evaluate science intelligently.
>
> (Gross and Levitt, 1994, p. 4)

I will argue in this book that this view is too sanguine, and that science itself is threatened precisely because it is dependent upon teachers and schools for its promotion. And that in New Zealand the official science education establishment gives succour to more wide-spread anti-scientific tendencies by its attack on scientific objectivity, rationality and realism, and by its erosion of the distinctiveness of the scientific endeavour in favour of misguided egalitarian ideology that ‘everyone is a scientist’, and ‘different cultures have different equally valid interpretations of nature’. The science education establishment are clearly not doctrinaire anti-scientists with most being well qualified in science. However by diminishing the role of objectivity, rationality and truth-seeking in science, they play into the hands of the enemies of science; they weaken the grounds for principled opposition to irrationalism and superstition in society; and they erode one of the most precious achievements of the Western heritage.

The vitality of the scientific tradition depends upon teachers introducing children to its achievements, methods and thought processes. Without teachers there are neither scientists nor scientifically literate citizens. This fact is repeatedly underlined in the comments of the scores of brilliant Hungarian scientists who were educated between the Wars. In a recent book dealing with this period,[6] the Nobel Laureate Eugene Wigner, remarks:

> I wish to say at this occasion a few words on a subject about which we think little when we are young, but which we appreciate increasingly when we reflect on our intellectual development. I mean our gratitude to our teachers. ... Our gymnasium teachers had a vital presence. To kindle interest and spread knowledge among the young – this is what they truly loved. They were preoccupied with teaching and they impressed us all, not only with their array of facts, but with the intense and loving attitude they held toward knowledge.
>
> (Marx, 1994, p. 175)

In the same book, Valentine Telegdi remarks:

> In the everyday practice of education we have to strive for truth. The knowledge obtained by students is proportional to the knowledge of the teacher, and is proportional also to the intention of transferring it. ... When the Hungarian scientists abroad think with gratitude of the Hungarian gymnasium and teachers, then the praise is right. ... In the US there is no real high school. Until the age of 18 children learn very little, the main goal of schooling is ‘social adjustment’. It may be that the abundance of excellent Hungarian scientists is not remarkable at all. We may be surprised that there are good American physicists as well.
>
> (Marx, 1994, p. 180)

The contrast with constructivist models of teaching – where subject-matter competence is discounted, and where it is explicitly stated that knowledge cannot be transferred from teacher to pupil – is palpable.

Constructivist Influence on Science Education

Constructivism is a major influence in contemporary international science and mathematics education. A former president of the U.S. National Association for Research in Science Teaching (NARST) has said that

‘A unification of thinking, research, curriculum development, and teacher education appears to now be occurring under the theme of constructivism ... there is a lack of polarised debate’ (Yeany, 1991, p.1). The immediate past president of NARST has edited a nineteen-chapter book titled *The Practice of Constructivism in Science Education* (Tobin, 1993), the Preface of which tells us that ‘there is widespread acceptance of constructivism’, and that ‘constructivism has become increasingly popular ... in the past ten years’. A 1990 bibliography produced at Leeds University, a major centre of constructivist research, listed over 1,000 works (Carmichael, *et al.*, 1990). Reinders Duit, at the Institute for Science Education in Kiel, has been performing the Herculean task of keeping up-to-date with research in this field, and his estimate is that there are currently 2,500 constructivist-inspired scholarly research articles in journals (Duit, 1993). There seems little reason to argue with Peter Fensham, one of Australia’s leading constructivists and science educators, when he claims that ‘The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning’ (Fensham, 1992, p. 801).

New Zealand’s official science education establishment has been dominated by people maintaining constructivist views of learning, teaching and science. Further, this small establishment – perhaps less than half-a-dozen depending upon how you identify key people – has been in the enviable position of having national influence on government policy and curriculum development in virtue of their chairing of government committees, membership of writing teams, the holding of teacher-development contracts, and so on. The few non-constructivists in the country have never been included in the official ‘loop’.[7]

Since the mid-1980s constructivist learning theory has dominated formal pronouncements, curriculum projects and Ministry-funded research programmes in New Zealand school science education. This can be seen in the four major Learning in Science Projects (LISPs) conducted by the staff of the Waikato Science and Mathematics Education Research Centre (SMER). Constructivism has become the ‘official line’. Whilst becoming the official line, constructivism has evolved from a debatable theory about how children learn science, to an all embracing theory of knowledge (epistemology), of curriculum, of teaching, of teacher development, and of education.

New Zealand constructivists are offering not only a new approach to science teaching, but a whole new approach to education, to the understanding of knowledge, and to the role of teachers. As one of the world’s leading proponents of constructivism has correctly said: ‘If the theory of knowing that constructivism builds upon were adopted as a working hypothesis, it could bring about some rather profound changes in the general practice of education’ (Glasersfeld, 1989, p. 135). This is obviously true, and New Zealand constructivists are working to bring about such profound changes. As Beverley Bell and other SMER staff have said:

> In taking into account the findings of the Learning in Science Projects, most teachers are challenged to change their implicit theories of students, schools, how children learn, the nature of knowing and knowledge, and the implications of these for teaching and learning activities in their classrooms.
>
> (Bell, Kirkwood and Pearson, 1990, p. 32)

The extent to which New Zealand constructivism has blossomed beyond its initial concern with children’s learning can be seen in one recent article by Beverley Bell, which makes pronouncements upon ‘A constructivist view of learning’, ‘A constructivist view of teaching’, ‘A view of science’, ‘Aims of science education', 'A constructivist view of curriculum' and 'A constructivist view of curriculum development' – to quote just the sub-headings of the article (Bell, 1991).

Another Waikato University constructivist has correctly drawn attention to the 'many parallels between the literature on the development of critical pedagogy [and] the literature on constructivist learning' (Gilbert, 1993, p. 35). And she rejoices that 'Critical theorists question the value of such concepts as individualism, efficiency, rationality and objectivity, and the forms of curriculum and pedagogy that have developed from these concepts' (Gilbert, 1993, p.20).

When university educators proclaim that rationality and objectivity are, *per se*, undesirable, then there truly has been a profound change in the educational climate; and one that, if widely endorsed, prefigures a profound change for the worst in New Zealand culture. The full magnitude of these changes are not yet apparent, but the recipes can be discerned in official documents and research reports, and some of the early, and unfortunate, fruits can already be seen in schools, colleges and universities. This book will point to some of these fruits and argue that constructivism has had a deleterious effect on the writing of the national curriculum, on teacher education programmes, on in-service education courses and in classroom teaching.

Constructivism's implications for the profession of teaching are dramatic. Two constructivists have recently said: 'Constructivist teachers view themselves as gardeners, tour guides, learning councillors or facilitators rather than dispensers of information or judges of right and wrong answers' (Roth and Roychoudhury, 1994, p. 27). Another constructivist has said: 'Most traditional teaching roles are not consonant with constructivist principles. To begin with the teacher would be a facilitator of student learning with understanding rather than a transmitter of knowledge' (Jakubowski, 1993, p. 139). Just how the teacher judges whether the pupil understands and how they convey this judgement to the student is left unanswered. The Introduction to a collection of constructivist papers arising from a research seminar contributed to by, among others, eight members of the Waikato SMER Centre, tells us that:

> One point to be considered was the use of the terms 'constructivist learning' and 'constructivist teaching'. Since all learning involves construction, we argued, 'constructivist learning' is tautologous. Some participants also wanted to avoid 'constructivist teaching', preferring to refer to teaching that takes account of the principle that each learner constructs personal meaning from experiences and instruction.
>
> (Fensham, Gunstone and White, 1994, p. 5)

These implications follow from the core constructivist thesis that, as Roger Osborne and Peter Freyberg stated in their canonical (for New Zealand science education) book *Learning in Science*, 'Knowledge is acquired not by the internalisation of some outside given but is constructed from within' (Osborne and Freyberg, 1985, p. 82). The current Director of the Waikato SMER Centre, Beverley Bell, echoed this claim when she said: 'knowledge is the personal construction of an individual and does not exist externally to be transmitted' (Bell, 1986, p.6). Another constructivist stated the position as: 'Starting from the assumption that our knowledge is a construction of ours, radical constructivism ... denies the possibility of knowledge transmission, even in principle' (Bettencourt, 1993, p. 40).

Adoption of this thesis clearly has flow-on effects for teacher education. In the traditional view, teachers had first to understand their subject, and then, with all the assistance of psychology, pedagogy, and personality, be able ultimately to convey that understanding to students. Traditional teachers rightly adjust their pedagogy to the circumstances, and students may have more or less responsibility for their own intellectual explorations. However if knowledge does not exist externally, or if it cannot be conveyed even if it does, then it is not clear why teachers should go through the difficult business of acquiring knowledge. This suits the ‘education is entertainment’ lobby, and untrained teachers and administrators who want to employ them, but it hardly advances traditional educational goals. Unfortunately some of these radical implications of constructivism are already being worked out in New Zealand teacher education establishments where process skills (tricks of the teaching trade) are replacing content mastery (subject matter knowledge) for both lecturers and students.

The incommunicability thesis of Osborne, Freyberg, Bell and others is so central to constructivism, and so wide-ranging in its educational consequences, that it warrants serious scrutiny rather than the mantra-like repetition it is normally accorded. To deny that knowledge exists externally is either to simply deny the existence of knowledge (surely a very radical claim for a science educator), or else to say that it exists only subjectively within the heads of individual learners. However, as will be argued later in this book, the beliefs of individuals can count as knowledge only when they are checkable against some extra-individual standard. So to assert the existence of subjective knowledge, as distinct from subjective beliefs, does indeed require standards, tests, criteria of knowledge external to the individual. All of this is perfectly sensible and orthodox, and one wonders what led constructivists to assert the non-externality and incommunicability thesis.

Karl Popper gave philosophical formulation to the traditional orthodox view with his division of existence into three domains: the first world, of material objects and bodies; the second world, of individual mental states and beliefs; and the third world, of cultural objects including scientific theories and knowledge (Popper, 1972). The third world is a human creation resulting from the exercise of mind (second world events), in conjunction with tools, typewriters, computers, experimental apparatus etc. (first world objects), but once created it exists independently of its creators. Cultural artefacts, language, theories and knowledge are not just inside the heads of individuals; they are not just states of mind; they exist externally to the individual. For Popper:

> ... even the subjective act ... of ‘understanding’ can be understood ... only through its connections with third-world objects ... such an act consists in the main of operations with third-world objects.
>
> (Popper, 1972, p. 163)

On this understanding, teachers mediate between students’ second world experience, their mental states and beliefs, and the third world, external, achievements of culture and science. Schooling is focused on second world events – children’s minds, beliefs and personal conceptual change, it is not focused on third world events – the generation of knowledge and objective criteria for evaluation of beliefs. Traditional educators can bridge the two worlds. Constructivists who deny the very existence of the third world, are in principle confined to the realm of personal experience and belief. Not a happy situation for science teachers whose subject matter mostly transcends experience and whose knowledge claims are so counter to everyday belief. Carl Bereiter, a cognitive psychologist sympathetic to constructivism, has recently noted that:

> we have found students taking World 3 objects seriously in a way that is distinctly Popperian and not adequately represented by other [constructivist] views. ... The important point, however, is that their focus is outward, on the objects themselves and the world they relate to, rather than on their own mental states or social roles. They feel a kinship with scholars and scientists, but it is a kinship based on shared goals, not on similarities of practice. To be of maximum help to students in this kind of endeavor, teachers need an epistemology that helps them distinguish between efforts dirercted toward the construction of knowledge and efforts directed toward changes in students' minds.
>
> (Bereiter, 1994, p. 23)

My contention will be that constructivism is does not provide the type of epistemology that Bereiter seeks: it denies the extra-subjective status of knowledge, and it routinely confuses knowledge with belief.

The Hungarians quoted above hold a 'traditional' view of education and of the role of the teacher. As Wigner said of his mathematics teacher, László Rátz: 'He knew the subject and how to kindle interest in it. He imparted the very deepest understanding' (Marx, 1994, p. 176). This is a sea-change from the image of facilitators, gardeners, and teachers reluctant to judge right from wrong opinions, from the idea of teachers being *in principle* unable to convey information to students. Contrary to constructivist opinion, the traditional model is not to be equated with dogmatism or unthinking conformity. As Cornelius Lanczos, another Hungarian scientist and a student at a Cistercian Gymnasium where Latin, mathematics, art, languages and science were all compulsory, said:

> I have obtained an education of high level. It was not a question of what one learned but the attitude that accompanied the person throughout his life. We found it wonderful to be exposed to all those ideas that the human race created. This emotional aspect was especially important in the cognitive years spent in secondary school, in the years of puberty. ... By presenting essays which we wrote, we came to a framework of mind where our brain recognised the importance of debate.
>
> (Marx, 1994, p. 170)

Lanczos was a country boy from a small town, yet at school he and others were put in contact with 'all those ideas that the human race created'. Yet 'we succeeded to keep the distance from dogmatic thinking, because we had seen that the same issue had various aspects and we discussed those various aspects. We were used to that' (Marx, 1994, p. 171).

It is interesting to read in the fourth LISP project on Teacher Development how one participant spoke of her understanding of teaching prior to exposure to Waikato constructivism:

> ... those teachers I thought were effective at school were those who seemed ... very knowledgeable and put it across in the form that I could understand. And so I always strived in my teaching to try and put things across in a nicely structured form that made sense and had easily followed steps. I thought that was what a good teacher was.
>
> (Bell, 1992, p.7)

She was in for a surprise.

The Science Education Debates of 1989 and 1993

In New Zealand, and elsewhere, there is generally a surfeit of discussion about educational funding and management issues, but far less public discussion of the purpose of schooling, the role of teachers, and the aims of education. The science education debates of 1989 and 1993 refreshingly raised questions about the nature of science, the role of teachers in education and learning, the place of tradition and the history of ideas in education, the place of gender and ethnicity in the appraisal of knowledge claims, and about the role of schools in the transmission of public knowledge and culture.

The 1989 Debate

The very public 1993 debate was an amplification of a comparable debate in 1989 occasioned by the preparation of the *Draft Forms 1-5 Science Curriculum.* The background to this curriculum was described by the government as follows:

> In 1985, the Department of Education began work on a new science syllabus which was eventually published in 1990 as the draft Syllabus for Forms 1 to 5. This document was based on the findings of the Learning in Science Project [LISP] undertaken by the Centre for Science and Mathematics Education Research at the University of Waikato. The project advocated a shift from the traditional presentation of facts to a more student-centred programme set in contexts familiar to students.
>
> (MORST, 1992, p. 23)

Beverley Bell, who directed the development of the syllabus, acknowledged that ‘my promotion of the constructivist view of learning and of the curriculum is well known’ (Bell, 1986, p. 9).

Unfortunately the 1989 debate was contained within ‘official channels’ and surfaced publicly only in provincial papers: it did not engage a wide cross-section of the country. It did, however, raise substantial educational and philosophical concerns that were still unresolved four years later. The 1989 debate well illustrates how the official science education establishment deals with contrary opinion: opponents are allowed to exhaust themselves in submissions, and are then finally ignored.

The Education Committee of the Royal Society of New Zealand commented adversely upon the 1989 *Draft.* It is noteworthy that its main criticisms were aired four years later by participants in the 1993 debate, although they had not read the earlier Royal Society report. Nothing had changed in the official documents. The Society said of the *Draft’s* definition of science, that:

> Science is based on observation, organisation of observations, and devising explanations. It is regrettable that there is no emphasis on the need to learn how to reason scientifically. It is not an innate process, but one that we struggle to acquire through learning.
>
> (Wells, 1989, p. 3)

Of the *Draft’s* purported aims of science education, the Royal Society said:

> The aim of ‘making better sense of their world’ is judgemental and should be replaced by ‘achieve a better understanding of their world’.
>
> (Wells, 1989, p. 4)

Of the section on Girls and Science, the Society commented that:

> This section is offensive to many scientists, including women. It is a sexist connotation that girls do not understand disciplines such as physics.
>
> (Wells, 1989, p. 6)

About the Learning in Science section, the Society observed:

> This section appears to be written for educationalists and is almost unintelligible to scientists. In most areas of science there are right answers and the authors should not encourage erroneous views. ... Little science can be learned by *watching* a laser show.
>
> (Wells, 1989, p. 6)

Concerning the Role of the Teacher section, the Society noted that:

> Listed are all the aspects of teaching that *any* good teacher has. ... [however] the duty of a teacher is to be knowledgeable in what he or she teaches. Most scientists believe that teachers do not have the scientific knowledge to do the job. The deficit in, for example physics, is cause for real concern.
>
> (Wells, 1989, p. 7)

On the important matter of Maori Science, the Society asked:

> Do the authors really claim that an alternative body of science (Maori Science) exists, is documented, is available to be taught as an alternative to Western science, and that the Department of Education has the people, knowledge, skills, and resources to teach this as an alternative?
>
> (Wells, 1989, p. 1)

And on this matter the Society believed that:

> The general tones in the syllabus are condescending and insulting. The statement, ‘Maori people do not see science as something separated from everyday skills, knowledge, attitudes, and values’ reflects a child’s holistic view. ... We do not want to introduce mysticism into science, but try to teach a base for science.
>
> (Wells, 1989, p. 5)

All of these substantial points were raised yet again in 1993.

Dr Gwen Struik, an ecologist, school teacher, university lecturer, and representative of the Nelson Education Board on the Forms 1-5 syllabus committee, made submissions in 1988 and 1989 on the *Draft* syllabus. She said of the process of development of the Forms 1-5 curriculum that:

> I had the feeling I was swimming in a sea of fluff when I was at those meetings ... they were like brainwashing sessions ... they go back to the Department and continue the brainwashing ... the whole trivialisation of science that runs through this document drives me up the wall.
>
> (Struik, 1989)

Dr Struik complained that she and other members of the Advisory Committee were only given 'summaries' of the public responses to the various curriculum drafts and discussion documents, and were denied access to the actual returns. In August 1988 she made a long submission on the *Draft*, which among other things, said of its examples of science that:

> Science is NOT about 'growing plants', 'making toffee', 'making concrete' etc. All these examples are technology or hobbies, not science. They could be introductory to a science activity, but only if they are linked into an investigation which asks questions, hypothesises, organises and makes a logical summary. ... Science is NOT about 'people' – there are other disciplines which specialise in people, eg. social studies, history.
>
> (Struik, 1988, p. 3)

In one submission of May 1989 to Dr Beverley Bell, she said:

> I continue to be very unhappy with it [the draft document] for many of the reasons I outlined in my August 1988 letter ... The total impact of page 7 is one long trivialisation of science, as in paragraph 4 'We are all scientists'. This is not true. Scientists are those who contribute to scientific knowledge. Would you say everyone who made a noise is a musician? ... Scientific knowledge can be gained by non-professionals, but such knowledge becomes science only when it is incorporated by formal and recognised methods.
>
> (Struik, 1989)

After three years of frustration, and having numerous submissions ignored, she resigned from the Advisory Committee.

Dr Warwick Don, a senior lecturer in Zoology at the University of Otago, made a submission criticising, among other things, the *Draft's* statement that 'Teachers need, in their teaching and learning activities, to .... acknowledge the beliefs, values and heritage of Maori students'. He said that:

> ... science is conducted irrespective of the cultural milieu of its participants. The recognition of any 'cultural context' in a science syllabus only introduces an irrelevance which will inevitably distort and could even destroy the very fabric of science education. Lysenkoism [in the former USSR] and 'scientific creationism' graphically illustrate what can happen when non-scientific ingredients permeate the process.

(Don, 1989)

He concluded by saying that:

> It is most regrettable that for the sake of satisfying certain political or social requirements, the integrity of science education at Forms 1-5 level is being compromised. An aim of science education is surely to produce an informed student body, not add to the high level of misunderstanding already rife in the community where science is concerned.
>
> (Don, 1989)

Professor Jack Dodd, the national president of the Royal Society, said in a statement to the Society, that:

> Parts of the draft can only be written by people who do not understand what science is, let alone what science is about ... there are patronising remarks about Maori and girls ... science is universal. The observations and laws are the same whether you live here or on the moon ...whether you are male or female, rich or poor, Jew or Gentile, black or white, Maori or pakeha.
>
> (Dobson, 1989)

The *Otago Daily Times* followed this statement with an editorial saying that Professor Dodd's comments 'raise questions about whether we have become too insular and protectionist in our general outlook' (2 August 1989).

It seems that none of these crucial points were engaged with, and certainly not accommodated by the Curriculum Writing Team. The sources of complaint continue all the way through subsequent drafts of the Forms 1-5 syllabus, and reappear as fresh as life in the drafts and finally in *Science in the New Zealand Curriculum* (Ministry of Education 1993). It is noteworthy that Dr Beverley Bell in a long article on the process of development of the *Draft 1-5 Curriculum* barely mentions any dissent. Her article 'Science Curriculum Development: A Recent New Zealand Example' (Bell, 1990) mentions just the Maori science issue, saying that some respondents made 'racist comments' and confused 'science and science education' (Bell, 1990, p. 13). Dr Bell quotes scores of satisfied teachers who were part of the development groups (but not Dr Struik or others who might have resigned), and concludes that the teachers' comments are epitomised in the following one:

> I really enjoyed being part of the development group. It personally gave me a real boost to have the luxury of hours to discuss science and learning with a group of enthusiastic teachers. We have remained good friends.
>
> (Bell, 1990)

Thus, to the outside world, the development of the *Draft 1-5 Syllabus* appears as a glowing success story; another triumph of Constructivism to add to the host of other triumphs reported in the literature. This can then be cited in applications for further funding, and by others around the world in support of the model of curriculum development employed. However, the recognition of dissent is most muted in the report.

It is undoubtedly nice to spend hours in discussion and to form friendships. Any such process will be highly rated. However the inevitable high ratings do not necessarily mean that the process leads to any better understanding of science or of science education – a fairly basic methodological matter. And the unstructured process clearly does not suit all: Dr Struik said of the meetings, that she 'felt like she was swimming in a sea of fluff ... they were brainwashing sessions'.

The claims, for instance, of the Royal Society and Drs Don and Dobb about universalism in science are serious and have clear consequences for science pedagogy and specifically for the teaching of Maori students: they should not be dismissed as the remarks of a few racists. It would have been to everyone's advantage if these claims had been engaged with. For instance, Albert Einstein, while a great humanitarian, and acutely aware of the cultural roots and impact of science, nevertheless maintained the orthodox universalist conception of science, saying that the basic aim of science is 'the complete liberation of the physical world picture from the individuality of separate intellects' (Holton, 1975, p. 107). There are important philosophical and pedagogical questions raised by this issue, but they are not addressed in the official documents.

Others have commented that since the mid-1980s the Constructivist caravan just rolls on in New Zealand and critics are left like dogs barking in its wake. Although the proposed *Forms 1-5 Syllabus* was shelved in 1991 in favour of the new Primary to Form 7 national curriculum, nevertheless the first document cast its shadow over the latter. The government's 1992 report, *Charting the Course: Report of the Ministerial Task Group Reviewing Science and Technology Education* (MORST, 1992), said that:

> ... the curriculum direction embodied in the draft Forms 1-5 Science Syllabus should be regarded as a basis for curriculum development in science.

The 1993 Debate

The public debate of 1993 began with an article by Martin Hanson, an Auckland school teacher, in *The New Zealand Herald* (10 August 1993) titled 'High schools enter a make-believe world'. He claimed that there was a 'dumbing down' of the curriculum with the removal of demanding topics, and that this was having a deleterious effect on students and the calibre of the teaching profession. One week later Max Thomson, another Auckland school teacher, wrote an article, 'Assessment-based in wonderland' (*New Zealand Herald*, 18 August), complaining about the Achievement Based Assessment (ABA) regime which is to be used in all school subjects. He said that science learning allowed of quantitative, objective, assessment and that he 'cannot help but feel sorry for the generation of science students that this experiment is about to fail'. The Minister for Education, the Honourable Lockwood Smith, defended ABA in an article titled 'Curriculum change aims at excellence' (*New Zealand Herald*, 25 August).

My own *Herald* article, 'Curriculum reform degrades sciences', was published the following day and it became a focus of debate. I wrote there, as can be read in the Preface of this book, that constructivism was the doctrinal engine powering the supposed reforms of science education, and that it was a silly doctrine with unfortunate effects for culture and society as well as for science education. Many letters to the editor followed, including one curiously pointing out that 'the new science education is offered to all students, not only those privileged enough to follow the doctrines of Galileo and Newton' (Nicola Dowling, *New Zealand Herald*, 1 September).

The Minister's Advisory Group for Science Education, which includes most of the chief players in New Zealand's official science education community, published a reply to my article – 'Science advisers have a say' (*New Zealand Herald*, 13 September). The advisers affirmed that 'this new curriculum properly sees making sense as the important goal of education', and they saw the curriculum as 'a valuable direction for science education in this country'. The difference between myself and traditionalists on the one hand, and the educational power group on the other, is revealed when the advisers said that 'truth is a very slippery concept'; and they went on to reject the notion that science students should be 'given truths to learn', saying that this idea has 'confused students for a very long time'. Taken at face value, their article said that there are no truths that the scientific tradition can pass onto children. This seemed an odd position for the country's premier advisory group in science education to take. Do they really have doubts that the sun is at the centre of our solar system? That Newton's formulae for gravitational attraction holds for large bodies? That there is a genetic basis for the inheritance of many characteristics? That the myriad forms of life on earth are connected to each other through a process of evolutionary development? That oxygen does support combustion? That bacteria cause certain throat infections? The advisers' letter well illustrates the gravity of the educational problem facing New Zealand.

Joce Jesson, from the Auckland College of Education, published 'In defence of a new science curriculum' (*New Zealand Herald*, 3 September), which opened with the observation that 'The state of science in New Zealand is in a very dangerous downward spiral and students are moving away from science as a discipline'. However, contrary to Hanson, Thompson and myself, she thought that the new curriculum would reverse this trend. Old science was criticised for being élitist, exclusive and ineffective in developing a scientifically literate population. More letters were published.

Dr Lydia Austin, then a high school teacher, now a lecturer in Science Education at Auckland University, contributed a piece titled 'Science curriculum, science catastrophe' (*New Zealand Herald*, 8 September 1993) that pointed out the difficult and complex nature of the social issues that the new science curriculum asked students to study, or more accurately, have opinions about. She said that the modular nature of the curriculum inhibited the development of informed opinions on these matters; and further, that many children did not have the ability to grasp and evaluate the complex economic-scientific-social issues involved. The piecemeal approach also militated against the development of coherent and scientifically accurate ideas on traditional topics. The same day as Dr Austin's article was published, I gave a public talk at the University of Auckland attended by about 200 people. The address, titled 'Constructivism in New Zealand Science Education', was not published, but was widely distributed. Drs Carr and Bell replied to this paper, pointing out a number of factual errors in my address, but not, in my opinion, addressing the major points raised. Their reply, and my rejoinder, were the subject of a equally well attended meeting the following week.

E.W. Braithwaite in a letter, 'Decent science teaching' (*New Zealand Herald*, 22 September) observed that while encouraging students to build on their existing ideas and beliefs may be exciting and successful, the crucial question is 'But what counts as being successful?' He noted that no experiments that involved students dropping cricket balls and feathers would ever lead them to knowledge of the gravitational constant. He pointed to the gulf between everyday experience and scientific knowledge, a gulf that I maintained teachers had to assist students across.

Professor Warwick Elley, University of Canterbury, picked up the assessment side of the debate in an article 'New Zealand education following a faulted model' (*Sunday Times*, 19 September), in which he observed that New Zealand was following the U.K. in adopting ABA, but the Dearing Report of 1993 had declared that ABA was not working in the U.K. and that £30 million had been wasted in trying to make it work.

My original *Herald* article was republished in Christchurch's *The Press* (27 September), which published the following day an article by John Longbottom (Christchurch College of Education) and Phillip Butler (Canterbury University) titled 'New school science curriculum leaves some aims ambiguous' in which, while defending the new curriculum, they said that 'the document gives no strong characterisation of what it means to be doing science, consequently the outcomes expected of a science course are ambiguous'.

My replies were made in a letter 'When making sense makes no sense' (*New Zealand Herald*, 27 September), in which I pointed out 'that a national science curriculum should label its learning areas "Making sense of the living world" and "Making sense of planet earth and beyond" instead of the simple "Learning about the living world" and "Learning about the solar system" indicates the dominance of constructivism in New Zealand'. A brief restatement of my position, 'Truth about science', was carried in the *Sunday Times* (10 October), and a slightly-reworked version of my original *Herald* article was published in *The Dominion* (12 October) under the title 'Science teaching off the rails'.

The columnist Frank Haden reviewed the debate for the *Sunday Times* (October 17) in a provocative article titled, 'New Age evangelists sneak into the science classrooms'. Professor Paul Callaghan, of Massey University's physics department, supported my views in an article 'Ethnicity, gender theories endanger science teaching' (*The Dominion*, 21 October). His particular concern was with the deleterious effects the new curriculum would have on physics teaching, saying that its 'changes are dressed up in grand aspiration, hopelessly unattainable'. He complained about the neglect of mathematics which is so essential for thinking and knowledge in physics, and about the assumption that children can discover for themselves what the great physicists of the past took lifetimes to discover. Finally, he complained about the assumption in the curriculum that 'physics should be driven by the personal needs of students, based on some fashionable notions of gender and ethnicity. The very universality of physics transcends race, gender, religion or political system'. Each of the matters raised by Professor Callaghan are central, and will be further canvassed in this book.

Ross Tasker, then the Ministry of Education's project manager for the science curriculum, wrote a defence of the curriculum, 'Science curriculum appraised', in the *Sunday Times* (24 October), in which he detailed the many people drawn from schools, colleges and universities who contributed to the curriculum, and repeated the claim that the curriculum was based upon internationally recognised constructivist learning principles.

Finally, a public seminar titled *The Crisis of Truth in New Zealand Education* was held in Auckland on December 4. This was attended by about 250 people, and contributions by, among others, Michael Irwin, Bruce Logan, Karl Stead, Robert Nola and Harold Turner were circulated.[8] Robert Nola's contribution identified constructivism as one manifestation of more widespread postmodernist thinking that is influential in the arts and humanities. The subtitle of his talk – 'The Decline of Knowledge in the University' – reflected his evaluation of these doctrines and their educational effects. He noted that 'the rejection of truth in knowledge runs far and deep. ... its rejection is part of the staple of the constructivist theory of education and of ... postmodernism'.

Another contributor to the December 4 seminar was Barry Seymour, a tutor in the Geography Department of Canterbury University, who for 15 years was a lecturer in science education at Christchurch Teachers College and before that had spent 20 years teaching science in primary and secondary schools. According to Seymour:

> there has been a longer term influence at work in the changing of primary and secondary science curricula: This is the substitution of methodology for content knowledge. This is seen in science syllabi in the period 1973-1993, and especially in Teachers Colleges' science programmes over this period. The same trend is discernible in the Advanced Studies for Teachers papers of the ASTU.
>
> The support of the old Department of Education for a standard methodology as a cure for the chaotic state of secondary science, and the completely ineffective state of primary science, in New Zealand schools in 1984, resulted in support for the LISP programme. The methodologists convinced the Department that they had the answer to the schools' problems.
>
> The Learning in Science Programme (LISP), together with the colourful and pretentious 1980 Science Syllabus and Guide has changed science at the primary school level from a useful environmental Nature Study (observationally based, and within the capability and general knowledge of primary teachers) into a playway time-filler interactive science, with children interpreting their own results in terms of their own limited and concrete experiences. Primary school science is degenerating into entertainment not education.

He identified lack of subject-matter competence on the part of primary teachers as part of the problem:

> Primary trainees have traditionally been accepted on the basis of excellence in gymnastics, ballet, music, life-saving, sporting achievements, together with speech, deportment and knowledge of current affairs and current social issues, rather than academic attainment in school subjects. In recent years some heed has been taken of attainment levels in mathematics, but little interest is shown by Selection Committees in levels of science attainment. My own experience at Christchurch Teachers College for 15 years was that many teacher-trainees had given up science after the core requirement, and very few had any Form 6-7 science background.

Seymour also thought the problem arose from Teachers College staffing policies, claiming that:

> Many science lecturers in New Zealand Teachers colleges from 1960 onwards were university graduates in Education. Their degrees were obtained part-time while teaching or by correspondence courses from Massey University. They were practising teachers with 'an interest in science' and this, together with their MA (education) was the basis for appointment. The pervading philosophy was that a degree in Education enabled you to teach anything and specialist subject knowledge was unnecessary. It was an expression of the practical New Zealand approach 'fix it with a piece of wire and she'll be right mate' which pervaded New Zealand society of the time. Consequently, with lack of science content,

> 'Methodology of Science Teaching' became the subject rather than science. As one teacher of the era said: 'We learned all the methods of teaching science, but no science'.

University Departments of Education did not escape blame:

> The eager adoption by University Education Departments of Bloom's Taxonomy of Educational Objectives as a gospel revelation in Education certainly had its effect on science education and the primary level. Bloom's ranking of knowledge as the lowest of Educational Objectives in his Taxonomy has had enormous effect on New Zealand primary schools, if only because of the disproportionately large numbers of teachers and lecturers and administrators with degrees in Education. How the other very desirable objectives of Bloom, such as Understanding, and skills such as Interpretation are developed without Knowledge remains unanswered. But Bloom provided the perfect cop-out for lecturers and teachers not to become involved in the very demanding work of gaining science knowledge.

Seymour's concluding comments to the seminar were sobering, and should focus the attention of all concerned with the health of New Zealand science education:

> Concerns must be raised about the outcomes of the LISP programme which has been imposed upon primary teachers without any discussion of its philosophy or its outcomes. The few critics of the programme in the late 1980s have been sidelined, and the Ministry of Education continues to steam-roll the programme under the auspices of a Minister who has no understanding of science education ('we now have a new science curriculum with chemistry and physics right down in the primary school'!).

Science teachers are responsible for introducing children into a great cultural achievement – a scientific approach to the world with its treasury of hard-won understanding. Constructivism impedes this introduction, and leaves teachers and pupils wondering why it should happen at all, wondering what is so special about science that one should endure the hard work of learning it, and possibly overturning comforting cultural beliefs.

Constructivism, as a theory of knowledge and education, was at the centre of the science debate. But science education is not alone in being influenced by this modern doctrine. In New Zealand, and elsewhere, mathematics, literature, social science education, and even theology education, are all to a greater or lesser degree affected by constructivist thinking. The science debate brought constructivism out of the academy, and onto the editorial pages and talk-back air-waves. For something so widespread and revolutionary in its influence, the public exposure and scrutiny of constructivism, which this book continues, can only be a good thing.

Elements of the New Zealand debate are, as will be seen in the next chapter, occurring in Australia. The NSW government has just released its draft Forms 7-10 science syllabus (*Outcomes and Pointers*, 1995), which incorporates the Federal government's National Curriculum Profiles. One commentator has said of the NSW draft syllabus that it:

> puts forward the view that it is not necessary to understand basic concepts, laws and known facts in science. There is a grab-bag of fashionable-sounding themes, mixed with liberal doses of social awareness, embellished with certain key words to make it sound like science. There is no mention of Newton's laws ... No basic knowledge of electricity and magnetism is required ... The words 'know' and 'learn' do not appear anywhere ... The problems in science are a manifestation of alarming developments in NSW education. Content is being reduced while warm-and-fuzzy 'activities', 'involvement', and toying with fashionable themes are taking the place of learning.
>
> (Gaudry 1995)

Liberal education opposes this trend. It recognises the intellectual achievement of science, and the difficult demands it makes on learners. But by placing the achievement of science in an historical, philosophical and personal context, its creativity and cultural impact can also be appreciated. The subject matter is learnt at the same time as a critical appreciation of science is developed.

CHAPTER 2

THE WIDER EDUCATIONAL CONTEXT

The argument about constructivism in New Zealand science education fits into a wider context of debate about the purpose of education and about the maintenance educational standards in literacy, numeracy and reasoning. The opening pages of the recently concluded three-year, Waikato conducted, Ministry of Education funded, LISP project, *Teacher Development*, is quite explicit about the overhaul of educational practice and thinking that constructivism requires:

> In taking into account the findings of the Learning in Science Projects [LISP], most teachers are challenged to not only change their teaching activities, but to change their implicit theories of students, schools, how children learn, the nature of knowing and knowledge, and the implications of these for teaching.
>
> (Bell, 1993, p. 4)

Jane Gilbert, Dr Bell's colleague, and contributor to the above report, is one of many constructivists who see in Critical Theory (as in Michael Apple and Henry Giroux's writing) the sought-for new illumination about learning, knowledge, schools and education. She sees it as constructivism's theoretical partner in the remaking of New Zealand education. This because:

> Critical theorists question the value of such concepts as individualism, efficiency, rationality and objectivity, and the forms of curriculum and pedagogy that have developed from these concepts.
>
> (Gilbert, 1993, p. 20)

Clearly New Zealand constructivism is not just about how children learn science. It promotes a new and all encompassing theory of education and teaching, the evaluation of which is vital to present education and to the future of New Zealand society.

It is notoriously difficult to read the educational winds. What might seem like a prevailing westerly turns out to be such only in a local pocket (Auckland). Or what appears as a prevailing easterly, turns out to be such only at great highth (Wellington policy) not at ground level (schools). Acknowledging this difficulty, there are nevertheless signs that New Zealand education is moving away from its traditional liberal concern with the development of knowledge and the introduction of children to established disciplines and, instead, is adopting a more United States-like approach to schooling where knowledge acquisition, and intellectual competence, are discounted in favour of personal development, job-training, forming correct attitudes, and school-based social engineering. This alternative to liberal education is an uneasy coalition between new-Right vocationalism and soft-Left political correctness.

Although more and more New Zealand students are spending longer and longer at school, there is evidence that the quality of this schooling is deteriorating. It is not just that because of increased retention rates there is a long academic tail in the final year of schooling. Even the top-end of the student range seems to be deteriorating. For example, Professor Alistair Fox from Otago University believes that English has not been adequately taught in schools for twenty years, and Canterbury University's English department estimates that fifteen per cent of Canterbury students cannot write properly.[1] It appears that in many quarters the educational plot is being lost: the rationale and objectives of New Zealand education are becoming confused, with teachers and administrators being less and less clear about what it is they are trying to achieve in school. This notwithstanding the efforts of the New Zealand Qualifications Authority to set measurable objectives for all stages of all programmes. There is a lack of clarity about what constitutes education, or even literacy. In this situation, where the purposes of schooling are not widely agreed upon, then schools and teachers are easy prey to political, business, social and fundamentalist religious interests that discount education and deprecate the development of informed and critical citizens.

There is no suggestion that constructivism is necessarily linked to non-discipline education or falling academic standards. Constructivism as a theory of human learning, the original heart of constructivism, is simply neutral on epistemological and educational issues. But in as much as constructivism expands to cover these wider issues, then it does tend, as will be shown in the following chapter, to give succour to non-disciplinary and non-rigourous education.

Weakening the intellectual content of education, and specifically science education, is particularly dangerous at the present time when, on the one hand, science is under widespread attack, and hosts of pseudo-scientific and irrational world-views are on the rise – travelling shysters, hot-gospellers, past-life therapists, crystal readers, astrologers, and the rest of their ilk, are filling circus tents (and their bank accounts). On the other hand, it is increasingly clear that scientific understanding is crucial for ameliorating all sorts of environmental and social catastrophes.

The Australian Situation

Australia’s proposed national curriculum has occasioned something of the same debate as New Zealand’s curriculum (Ellerton and Clements, 1993). One commentator has said that:

> What is wrong with the National Curriculum? The ‘science curriculum’, for example, is not science; it is sociology with an anti-science bias. ... Phoney or mendacious information on issues carry the day. Scientific principles are largely absent. ... The mathematics curriculum is years behind that of our competitors: Germany, Singapore, Japan, Switzerland, France, and so on. Most of the algebra and trigonometry is gone.
>
> (Baklien, 1994, p. 15)

Another commentator has said that ‘In Victoria we have the situation that mathematics and English classes are being discarded for sport and physical education’ (Guttmann, 1994, p. 6). Another has remarked that ‘The syllabuses currently coming into high schools will no longer provide an adequate basis for the training of doctors and engineers; guessing the number of jelly beans in a jar is not the sort of skill they require, but future high school students will spend plenty of time on such activities’ (Cowling, 1994). With the mushrooming of non-academic courses in Australian high schools, traditional discipline-based subjects have collapsed. In N.S.W. the number of Higher School Certificate students sitting the Contemporary English course, which ignores classic literature, but does cover advertisements and magazine stories, has grown from 2,000 to 18,000 in four years; while the number of students taking the traditional English course which deals with Shakespeare and pre-twentieth century writers, has dropped from 15,000 to 7,700 in the same time. The latter figure represents just 13 per cent of the school leaving class. That is, only one N.S.W. student in eight is currently doing ‘academic’ English in the Higher School Certificate. The remaining seven of the eight students have to all intents and purposes lost their life’s one opportunity to read, and be introduced to, good pre-modern literature. This trend is very much in the direction of U.S. schooling.

In 1992 the Australian Senate’s Employment, Eduation and Training Standing Committee’s report on literacy standards suggested that up to a quarter of young people finishing primary school cannot read or write adequately. The Australian Council for Education Research found, in 1988, that only 52 per cent of Year 5 students in the study were able to carry out everyday mathematics applications like calculating change from whole dollars and performing calculations with the level of complexity of 125 divided by 5. Sixteen per cent of year 5 students, in 1988, did not understand the concept of a quarter, as compared with only 9 per cent in 1980 (Penington, 1994, p.53). There is more to education than literacy and numeracy, but that is the core, and the prerequisite for higher educational aims.

Neither Australia nor New Zealand have caught up with the U.S. – where it is common to find university bookshops stacked high with Mills and Boon romances – but the direction of schooling, the educational winds, are clearly blowing towards the U.S. In 1995 a number of Australia’s new ‘universities’ were admitting students into their Arts faculties with a Tertiary Entrance Rank (TER) of 35. This is when a rank of 99 out of 100 is needed for entrance to Law or Medicine in the old universities. A score of 35 means not much more than the ability to write your name and address correctly. In this situation, maybe some Australian university bookshops will soon begin filling with Mills and Boon. And worse still, once honourable and nationally vital, technical and trade colleges will be empty because their students will be at ‘university’ doing Postmodernism One and Introductory Critical Theory.

Parallels with the United States

The United States provides a salutary example of what can happen when the academic goals of education are abandoned.[2] A few years ago it was estimated that half of all U.S. 17-year-olds could not find the area of a square when given the length of one side.[3] In the same year it was estimated that 30 per cent of the same age group could not identify in what half of what century the American Civil War occurred.[4] One observer, who spent a considerable amount of time in Los Angeles schools, was unable to find a single student who knew the years that World War Two was fought, and he only found two students who could place Chicago on a map of the U.S. (Hirsch, 1987, p. 6). In 1984 it was estimated that twenty-five million U.S. adults could not read the poison warning on pesticide cans much less the not-very-demanding front page of a tabloid newspaper, fully one half of black 17-year-olds were functionally illiterate, and that fifteen per cent of urban high school graduates could not read what was written on their testamur (Kozol, 1986, p. 4). In 1987 the National Science Foundation warned that ‘the nation’s undergraduate programs in science, mathematics and technology have declined in quality and scope to such an extent that they are no longer meeting national needs. A unique American resource has been eroded’ (Heilbron, 1987, p. 556). In 1991 the Carnegie Corporation said that U.S. technical education was so blighted that the situation ‘posed a chronic and serious threat to our nation’s future’ (Beardsley, 1992, p. 79).[5] Jon Miller, a long-time researcher of levels of scientific literacy in the U.S. estimates that only between five and nine per cent of citizens could be labelled scientifically literate (Miller, 1992, p. 14).

It may be thought that the U.S. situation is so abysmal that even to mention New Zealand in the same context is preposterous – New Zealand after all leads the world in child literacy and surely New Zealand school leavers can work out the area of a square if given only the length of one side? Yet of the 338 students who entered the Primary Teacher Education programme at the Auckland College of Education in 1991, fully 41 per cent (138 students) could not determine the GST (at 12.5 per cent) payable on a bill of $62, and 27 per cent (90 students) of the same primary intake could not work out the length of a pencil when its end was placed on the 2cm mark of a ruler (Buzeika, 1993, p. 36). These figures are just about as appalling as anything coming out of the U.S. And remember that the figures relate to New Zealand students who have successfully completed 12 years of schooling, have gained entry to a tertiary education institute, and are going to be school teachers!

The New Zealand Literacy Debate

Just as the New Zealand economy has long ridden on the sheep's back, so also has its high international education reputation ridden on its impressive literacy rates as measured by the periodic International Association for the Evaluation of Eduational Achievement. Professor Dame Marie Clay's Reading Recovery programmes are internationally known and adopted. But the link between literacy reputation and reality is being strained, and even the Reading Recovery programmes are being reappraised and seen not to be as wonderful as once commonly thought. Without making too much of it, there are some parallels between the New Zealand literacy situation and the whole language reading programmes proposed to enhance it, and New Zealand science education and the constructivist programmes to aid it. There is a literacy problem as well as a science problem, and in both cases the officially preferred cure is faulty.

Studies by Associate Professor Tom Nicholson of the University of Auckland have suggested a reexamination of the glowing IAEEA results. The high average literacy covers significant pockets of desperate illiteracy. His studies show that in South Auckland, only 8 per cent of 14-year-old students (75 out of a sample of 923) had reading levels above the 50th percentile for their age group as measured on a standardised reading test that was normed on a national sample of 10,000. This simply means that the overwhelming majority (92 per cent) of these students can barely read, despite having been in school for seven or more years. The results of middle-class students were, predictably, better. But not so better as to give great joy (Nicholson, 1993, 1994).

The bleak picture painted by Nicholson is supported by others. Kathy Kostyrko, the president of the National Association of Personnel Consultancies put the matter starkly: 'Young people coming out of school can't spell, can't write and cannot think for themselves ... everyone in the industry feels the same' (Chamberlain, 1993, p. 68). Jenny Chamberlain, a chronicler of the New Zealand literacy debate, has said that: 'New Zealand's illiteracy is a huge national problem bubbling away under the lid of our complacency, a problem we mistakenly believe we can ignore but which is about to boil up and burn us at any moment' (Chamberlain, 1993, p. 68). The English department at Canterbury University has documented the extent to which that university is already being burnt. It estimates fifteen per cent of Canterbury students need remedial assistance with writing. The vice-chancellor, Professor Bert Brownlie said 'its a deplorable situation to find students failing or not doing as well as they could because of an incapacity to express themselves in writing'. Professor Alastair Fox of Otago's English department sees a disturbing number of English students who cannot construct sentences and make gross errors in punctuation. He believes that 'you cannot teach literacy unless you can teach the grammar of English ... there needs to be a reconception of the way English is taught'. He is of the opinion that English language has not been taught adequately in schools for twenty years and universities had likewise neglected the teaching of English as language. William Richardson at the University of Auckland has observed of undergraduate essays that 'The spelling is all wrong and the number of students who have very little idea how to express themselves is disquieting. It seems to me we could get to the stage where we are producing a whole lot of people who have no idea how to express themselves on paper' (Chamberlain, 1993, p. 73).

My own experiences at Auckland support Richardson's observations. Whilst I was privileged to have some of the best graduate students I have ever encounted, I also had graduate students who could not write, who could not spell, who did not know the purpose of paragraphs, and who had little idea that academic essays are not merely streams of consciousness, but should have some structure that relates evidence to conclusions. I read a number of PhD proposals that were so ill-written and jargon laden as to be unintelligible; and where they were intelligible they were filled with *non sequitur* argument. Students were unable to distinguish an assertion from an argument. These students were bright enough, but their education had failed them: they had been educationally short-changed. They had not been taught how to organise their ideas, how to think logically and how to communicate clearly: their minds, despite years of education, were scrambled.

These Canterbury, Otago and Auckland students are the best of New Zealand school leavers: if they cannot write sentences, and organise their thoughts, then what of the rest of the school leavers. Fox believes that the problem of illiteracy in New Zealand is 'all pervasive'. This means that the problem of 'scrambled thinking' is equally all pervasive: clear thinking and clear writing are related. If undergraduate minds are scrambled, then schools and universities have not done their job. Rational minds do not grow like plants unfolding from within; their development is dependent upon initiation into public forms of thought that have standards of competence. This initiation, hopefully by teachers who know, care for, and manifest competence in reading, writing, arithmetic, cooking, art, science, sport, and all the other subjects, is the main purpose of schools.

The threat that Richardson foresaw of producing 'a whole lot of people unable to express themselves on paper', has been made more probable by, as reported to me by two primary teachers, the Ministry of Education discouraging comprehension exercises in primary schools. As one of the teachers said, 'I would be fired if I did comprehension with my class'. These exercises are one means of developing habits of attentive, logical and disciplined reading: who said what? What did they mean? Why did they say it? They also inculcate habits of analysis, reasoning, and clear thinking. Without the training and practice that old-fashioned comprehension exercises provide, it is likely that reading becomes, at best, just entertainment; a matter of having warm or cold feelings about the text; reading loses its power to develop the analytic and logical structures of the mind. To abolish comprehension, and its associated practices of analysis and reasoning, is one sure way of producing a nation of people who cannot think clearly, and who cannot comprehend. This has catastrophic cultural, political, and personal, to say nothing of economic, consequences. Minimally it destroys the capacity for critical appraisal: to critique an argument, or proposal, depends upon being able to comprehend what it is. If a nation cannot comprehend, then it is easy prey for self-serving politicians, shysters, con merchants and ideologues of all shades.

George Orwell drew attention to these matters in his masterful essay, ‘Politics and the English Language’ where, drawing on examples of current political writing and social commentary, he observed that:

> The writer either has a meaning and cannot express it, or he inadvertently says something else, or he is almost indifferent as to whether his words mean anything or not. This mixture of vagueness and sheer incompetence is the most marked characteristic of modern English prose.
>
> (Orwell, 1945)

The decline of comprehension exercises and the lack of attention to writing skills are in part a consequence of the adoption of constructivism in literary theory, wherein texts do not have meaning but meaning is generated by the reader. This thesis is also a mainstay of New Zealand science education. According to naive old-fashioned thinking, authors had intentions in writing texts, and the texts they wrote had a primary meaning which was connected to those intentions and the meaning of words they used (they may well have had secondary or even deeper meanings that the author was not aware of, but that is a different discussion). Reading required attention to the author’s words, and effort at understanding what was being said. Mature reading guarded against importing into a text the reader’s own assumptions and values; anachronistic reading was to be avoided; texts were to be understood in their own terms. Certainly the reader was encouraged to evaluate the text and the author’s message, and also to explore what meaning the text had for them, but first the message had to be understood in its own terms. The original meaning had to be understood before the reader’s meanings were explored. This was part of what respect for the text and the author required. Thus comprehension exercises had a purpose. However with the rise of constructivism, all of this becomes otiose.

When these traditional concerns are abandoned, so also is the possibility of learning from other cultures, from the past, and from the insight of good authors. If meaning is limited to what we already know and understand, if the message of an author or poet is merely what we make of it, then the opportunity for expanding our horizons and understanding is lost. *The Australian National Statement for English*, says that ‘texts will have different meanings for different people’. This is simply ambiguity and evasion dressed up as principle; it is arrogance masquerading as modesty. To listen to, and learn from others, requires that we have the humility to attend to what *they* are saying; it requires that we not put our words and understandings into their mouths. Constructivism undermines the traditional enlightening and mind-expanding function of good literature.[6]

The New Zealand English Curriculum

Professor Karl Stead has drawn attention to the severe shortcomings of the *Draft New Zealand English Curriculum* (Stead, 1994); shortcomings of theory and execution that are alarmingly comparable to those of the Science Curriculum. He says that the document is ‘designed to foster social accommodation and amelioration rather than excellence. It continues the tendency of recent years which has made the study of English more therapeutic than academic’ (p. 1). Stead comments that ‘English is at the core of the whole educational process. It is the means of communication and understanding on which all else is constructed’, and observes, that the quality of English teaching affects ‘the whole intellectual life of the community, and also the degree to which as a group we function successfully in the larger world’ (p. 1).

Going back nearly one century, Stead quotes from the 1904 Primary English syllabus which maintained that:

> The chief objects of the instruction in reading shall be to impart to the pupils the power of fluent reading ... and expression based upon intelligent comprehension of the subject-matter; to cultivate a taste for and an appreciation of good literature and accordingly to lead pupils to form the habit of reading good books ...The object of the instruction in composition shall be to train the children in the correct and ready use of their mother-tongue, both in speech and in writing.
>
> (Stead, 1994, p. 21)

He contrasts this admirably straight-forward, clear, and succinct statement of aims, with the comparable, muddle-headed, statement of the 1993 English *Draft:*

> In planning programmes, and in assessing and evaluating language development, teachers and learners should therefore focus on both the products of learning and on the means by which learning occurs. Learners should develop self-evaluation skills to help them become self-directed in their use of language.
>
> (Stead, 1994, p. 22)

How self-evaluation is possible without other-evaluation is not explained. Evaluation requires standards or exemplars against which one evaluates. People cannot self-evaluate without being taught correct spelling and grammar, and being given examples of good literature, and clear writing. Much writing is passable until it comes into contact with truly clear and elegant expression; without a focus on, and concern with, the latter, the former becomes the accepted norm. Mediocrity spreads. Its spread is only aided by directives such as that given to the 1993 Minister of Education-convened conference on 'The Role of the Senior Ssecondary School in the 21st Century' where it was stated that 'In the 21st century teachers would be concerned with students and their learning, rather than the teaching of students' (*New Zealand Herald*, 25th August 1993, p. 8).

Stead laments the *Draft's* lack of 'frankness, directness, and clarity'. It is little consolation for him, and other New Zealanders who share his concern about educobabble, to read that the recently released N.S.W. *Official Handbook of Grammar for Teachers of English K-6* advises that:

> Explanation and information report tend to use either a positive or negative polarity or a high modality as they account for the certainty or usuality of phenomena.
>
> (p. 30)

This passage, if the situation were not so tragic, would be laughable. What has happened when an education establishment can produce such turgid muck, have it rise to the surface, and become enshrined in an official government Handbook? The authors of such tripe can hardly complain about the low esteem that society has for educators: they are in part responsible for it.

Bertrand Russell in his *Autobiography* made a nice observation about ethics and clear thinking. As New Zealand moves away from comprehension exercises in schools, and substitutes turgid obscurity for clear prose in its official education documents – it is worth repeating:

> Ever since puberty I have believed in the value of two things: kindness and clear thinking. At first these two remained more or less distinct; when I felt triumphant I believed most in clear thinking, and in the opposite mood I believed most in kindness. Gradually, the two have come more and more together in my feelings. I find that much unclear thought exists as an excuse for cruelty, and that much cruelty is prompted by superstitious beliefs.
>
> (Gross and Levitt, 1994, p. 1)

The Politics and Theory of Reading

Tom Nicholson, speaking of the theory of reading that led to the staggering illiteracy levels revealed in his studies, said:

> In the proposed new English curriculum, however, the present system will be well and truly engraved in every teacher's reading programme ... It's an appalling prospect, because the theory behind the curriculum statement (ie., constructivism theory) is wrong. There are dozens of research studies which are critical of this theory. But the curriculum-makers in the Education Ministry are immune to such criticism.
>
> (Nicholson, 1994)

His remarks echo my complaint about New Zealand's science curriculum, its underlying theory, and its advocated methods of instruction.

There is an international debate on reading acquisition between adherents of phonic versus whole language instruction (see the literature in Adams 1990). New Zealand has officially endorsed the latter, constructivist approach; it is the basis of the Reading Recovery programme; it is mandated in the Ministry of Education's *Reading in Junior Classes* teachers' guide. Phonic instruction is just about outlawed in New Zealand schools. The fact that fully 28 per cent of all 6-year-old pupils in New Zealand have to go into the special Reading Recovery programmes – that is, almost one in three 6-year-olds are deemed not to be able to adequately read for their age and are in danger of missing the reading boat – should suggest to the Ministry that the official whole-language approach to reading is not working terribly well. The suggestion seems not to have been taken up.

Evaluation of the theory and practice of whole language and Reading Recovery approaches to literacy is beyond the scope of this work on science education, and beyond the author's professional competence, but there are pressing educational and political similarities in the two fields that deserve mention. In both cases the official establishment seems not to be interested in contrary opinion or evidence. In both cases 'feel good' and politically correct analyses seem to have preference over research where hard-headed comparisions with alternatives and measures of cost-effectivness are made. In both cases there seems to be no concern for the kids that the preferred system fails. New Zealand critics such as Tom Nicholson at Auckland and Bill Tunmer at Massey have pointed out, as have others overseas, that Reading Recovery does not systematically address essential metalinguistic skills, such as phonological awareness, phonological recoding and syntactic awareness, which are considered to be directly associated with skilled fluent reading (Tunmer, 1990, Tunmer *et al.* 1988). Vivianne Robinson at Auckland has criticised the evaluations done by Dame Marie Clay of the effectiveness of Reading Recovery. Robinson comments that many Reading Recovery students fail to learn the basics of reading and so remain 'vulnerable to the contingencies, expectations and opportunities provided by the classroom teachers' (Robinson, 1989, p.42). Macquarie University researchers have refined and endorsed these criticisms, saying that:

> There are obvious dangers in the widespread use of a programme ... which has not received the benefits of stringent empirically based evaluations. This is not unusual for educational innovations, which are famous for their cycle of early enthusiasm, widespread dissemination, subsequent disappointment and eventual decline – the classic swing of the pendulum.
>
> (Center, Wheldall and Freeman, 1992, p.263)

Their research on the failings of the embryonic New South Wales Reading Recovery programme suggests:

> these results do add to the growing literature on the need to develop instructional programs in phonological awareness, phonological recoding and syntactic awareness in the very early years of schooling.
>
> (Center *et al.*, in press)

Just the programmes that are discouraged, if not outlawed, in New Zealand.

It is obvious that constructivist approaches to both reading and science will work with well-to-do children from literate homes, whose parents manifest and encourage reading skills and investigation: in these situations just about any approach will work. But it should be equally obvious that for kids from Struggle Town, whole language constructivism will not work. This is what Nicholson showed in his South Auckland studies. It is what the large Australian welfare group, The Smith Family, has shown in a 1994 national study. The Smith Family found that 60 per cent of the 500 high school students in its sample of welfare homes had a reading age of 10 years or less. The research director, Elizabeth Orr, believes that:

> the way children have been taught to read may have been making it harder than ever for disadvantaged kids to catch on. ... [there] are serious doubts about using the 'whole word' approach to teaching reading in the early school years. The dumping of the phonetic approach – sounding the word out – means children have no structure to hang onto.

Against whole language approaches, she says:

> this may not work for kids whose lives already lack structure and whose parents, coping with unemployment, desertion, violence or illness, may not feel like a cosy read at night.
>
> (*Sydney Morning Herald*, February 4 1995, p.5/2)

Mr Stuart MacLachlan, a South Auckland primary principal said, during 4th December 1993 public meeting on 'The Crisis of Truth in New Zealand Education', that 'the new maths and science was simply a device by the white middle-class to impede the educational progress of coloured minorities'. These are clearly not the intentions, but the results might be as the principal feared. The continued advocacy of teaching methods that wreck such havoc on working class children (but not of course on the children of the advocates, who are comfortably middle class, and frequently attending private schools) cries out for investigation.

A Window into New Zealand's Educational Predicament: Trainee Teachers' Mathematical Incompetence

The grounds for much of my ill-ease about New Zealand education are dramatically illustrated in a study by Anne Buzeika (Buzeika, 1993) of the mathematics ability of students entering the Primary Teacher Training programme at the Auckland College of Education in the years 1991 and 1992. The study reveals an appalling level of mathematical ignorance among these future teachers, and a devaluation of the educational standards required for the teaching profession, that verge upon a national scandal. The contrast with France, where Primary school students study calculus, and with Hungary, where Primary science teachers are required to study sophisticated physics for four years, is sobering. Buzeika's data on gross mathematical incompetence among trainee teachers should concentrate the minds of politicians and educators.

Anne Buzeika tested the performance of incoming Primary students on a brief test of mathematical competency. The results of this test had some, but not much, influence on whether students were selected into the College programme. The test was pathetically simple, being pitched at an upper-Primary or lower-

Intermediate level of competence. There were 338 students in the 1991 intake (66 male, 272 female), and 353 students in the 1992 intake (83 males, 270 females). Ethnically, of the 691 students in the two intakes, 480 were European, 105 Maori, and 106 other nationalities. The 1991 test had twelve questions, the 1992 test had fifteen. In order to lessen supposed test anxiety and novelty effects, a version of the test was sent to all prospective students some weeks before the College test and interview, and students who wished to, could bring relatives to sit with them during the test.

The 1991 test consisted of the following questions:

1. This list shows what Sharon bought at Foodtown:

Baked beans	$1.29
Toothpaste	$2.05
Vegemite	$1.77
Muesli	$3.85
Potatoes	$3.98
Milk	$2.34
TOTAL	$____

What amount should go in the TOTAL box?

2. Because 1 cent and 2 cent coins are no longer used, Foodtown obtains the balance due by rounding the total *down* to the nearest 5 cents.

What amount goes in this BALANCE DUE box?

TOTAL	$170.09
BALANCE DUE	$_____

3. Matapa pays for a pizza with a $20 note. The pizza costs $16.35.
How much change should she get?

4. (a) How much will 8 fillet-o-fish cost at McDonald's?

Hamburgers	$1.25
Cheeseburgers	$1.35
Fillet-o-fish	$2.75
Quarter pounder	$2.95
McFeast	$3.25

(b) Seven friends shared the bill equally after a meal at McDonald's.
Altogether they paid a total of $43.75.
How much did each pay?

5. The table shows the time taken by four athletes to run 200 metres.

Carl	19.90s
Ben	20.01s

Lyn	19.89s
Emil	20.10s

Write the placings in order: 1st, 2nd, 3rd, 4th.

6. The height of a door to a room is about:
   58cm,
   108mm
   2m
   120cm

7. (a) How long is this pencil?

Drawing of a pencil against a ruler

   (b) How long is this pencil?

Drawing of pencil against a ruler but with pencil end on the 2cm mark

8. What was the time 37 minutes ago?

Picture of a watch showing 12.03

9. A calculator shows 94.023

Meli realises that the simplest way to change the 4 to a 7 is to press the following keys:

+ 3 =

What keys would he press for the simplest way to change:

(a) the 3 to an 8?

(b) the 9 to a 2?

10. After travelling 100km, the odometer (mileage indicator) on a car shows: 1009
    What did the odometer show before the journey?

11. Sandals cost $62 before GST.
    How much will the sandals cost including GST at:
    (a) 10 per cent
    (b) 12.5 per cent

The results on this test were, for students who had finished high school and were entering into tertiary education, disturbing, to put not too fine a point on it. The more so when it is recognised that Primary teachers are teaching mathematics for some part of most school days. The following table shows the percentage, and number, of the *intake* who answered each of the above questions incorrectly. Remember that these figures apply to the intake, not to the cohort who sat the test and then were denied entry to College. In other words the following results were those of the *successful* students, those 338 students who gained entry to the Primary programme at Auckland College of Education. The results of the *unsuccessful* candidates (if there were any), are best not thought about.

Question	**Percentage Incorrect**	**Number Incorrect**
1	7	22
2	12	41
3	5	16
4a	12	39
4b	14	46
5	4	12
6	28	95
7a	19	63
7b	27	90
8	17	56
9a	12	40
9b	12	39
10	18	62
11a	13	43
11b	41	138

Thus, from the results for question seven, 19 per cent of the intake into primary teacher education could not measure the length of a pencil placed against a ruler with its end on the zero mark, and when the end was placed on the 2cm mark, this figure jumped to 27 per cent. And from the results for question eleven, we see that while 13 per cent of the intake could not work out 10 per cent of a figure, when the calculation involved 12.5 per cent, or 1/8th, the error rate jumped to a staggering 41 per cent. This suggests that almost half of the students basically did not understand anything of percentages or fractions, which raises questions about what they had been taught during their twelve or so years at school.

The 1992 intake did worse overall on a comparable test than their predecessors! Forty-one per cent, or 144 students, could not answer the following question:

> Gweneth bought 4.15 litres of unleaded petrol for her motor mower. She paid $3.69 for the petrol. Gweneth should use which one of the following calculations to check the price for one litre?
>
> (a) 4.15 + 3.69 (b) 3.69 4.15 (c) 4.15 - 3.69
>
> (d) 3.69 - 4.15 (e) 4.15 3.69 (f) 3.69 x 4.15

This particular result reveals a massive failure of mathematics education in New Zealand schools – 41 per cent of the intake were unable to even think in simple mathematical ways, quite independently of technical calculating ability. Remember that the results above are for the successful candidates. They are the results of students who have finished high school and have gained entry into a tertiary college.

Of the 1992 intake, 140 students (40 per cent) could not work out the following question:

The following table shows the corresponding local times in Perth and Adelaide:

Perth	Adelaide
7.43 am	9.13 am
11.14 am	????

What time goes in the box?

The College regarded a score of 5 or more as satisfactory performance in this test. For some sense of comparison, I gave the 1991 test to a 10-year-old girl in the 5th grade of a N.S.W. school. She got all questions correct in about 10 minutes, without the benefit of any anxiety-reducing pretest trial.

Buzeika suggests an explanation for these results when she observes that 'most of our students have experienced [in schools] a content based programme with little focus on the mathematical processes. Many have forgotten how to think in mathematics' (p. 12). She is hopeful that this problem will be addressed by the new *Mathematics in New Zealand Curriculum (1992)* which 'supports a constructivist approach to the teaching of mathematics' (p. 11), and which requires, as one commentator said, teachers to 'encourage presentation and discussion of conflicting points of view together with the skills to work toward consensus in which various mathematical ideas are coordinated' (p. 11). One can only think that it must have been the very worst type of content teaching to produce such mass mathematical ignorance as her study reveals. French and Hungarian students have high mathematical competence despite non-constructivist, content-focused teaching. They are taught content with understanding. Buzeika's ACE students are not within a bulls-roar of constructively, or any other way, facilitating the development of mathematical competence in students. As she herself remarks, 'teachers need to understand mathematics deeply themselves if they are to facilitate children's development of "power and control" in mathematics' (p. 12). This deep understanding, which manifestly was not attained at school, will have to be attained at ACE. It is not clear that this happens.

The main purpose of the Buzeika study was not to ascertain the entry-level mathematical skills of the Primary trainees, but to compare their scores with their scores on tests at the end of their first year mathematics papers at the college. She wanted to know to what extent the entry test was a predictor of college mathematics success, and thus whether perhaps the entry test might be abolished. The first semester college mathematics paper for Primary teachers (625.100) deals with number and measurement, whilst the more difficult second semester paper (625.200) deals with fractions, decimals and percentages (remember that Primary school students in France are studying calculus). For the 1991 group, of those who scored 10 out of a possible 15 on the entry test, 100 per cent passed 625.100, and 100 per cent passed 625.200; of those who scored 8 out of 15 on the entry test, 100 per cent passed 625.100, and 67 per cent passed 625.200.

These figures can only suggest that the first year mathematics standards at ACE are woeful. This judgement is confirmed by interviews that Buzeika conducted with the students. One student, who scored 3 out of 12 in the 1992 test and yet passed first year, said:

> *I don't really like maths. I don't think they should use my mark to stop me coming to College. I am glad they didn't.*

It is sobering to think that this student is probably now teaching mathematics in a primary school somewhere. Another student, with a test score of 5 out of 12, and who scored a merit in first year, said:

> *I took the practice test to a friend of mine and got help but obviously I didn't get very good help. I thought I would have done really well in it because it was a parallel test. I can't believe I only got 5. ... I don't think you can use the score to predict what someone will do in College courses. ... Our lecturer put us in the context of children and how children learn and then he involved us in group work so we got to see how different people worked things out.*

Another student, with a test score of 6 out of 12 and who scored a distinction in first year, when asked to comment on the disparity of her grades, said:

> *The score doesn't surprise me really ... if I had been taught these things I would have been able to do them. I was doing the test on my own – there was no-one there to ask questions of, to help me out, to explain the questions to me if I didn't understand what to do.*

These comments invite the thought that maybe the ACE first year mathematics papers are easier than the entry test. If so, there is a complete trivialisation of tertiary education occurring in New Zealand.

That there is even talk of abolishing the pretest because it fails to predict first year performance is sadly typical of common reactions to problems in New Zealand education. The obvious alternative would be to demand a satisfactory level of performance, not on the entry test, but in, minimally, School Certificate Mathematics. Students should not be able to enter Primary Teacher Training without an A or B in the School Certificate, or a B or C in the Bursary Exam. The insistence on such minimal standards might begin to redress the falling public esteem of the teaching profession. It can only diminish the status of education for the community to see that people who cannot work out the length of a pencil when placed against a ruler, or ascertain the price of a litre of petrol given the total cost and number of litres put into their car, are nevertheless accepted into, and are progressing through, Primary teacher training. Further, it takes away the incentive to master mathematics at school. Students realise that you need not bother learning to add up or to divide, much less master any higher mathematical skills, because you can always become a Primary school teacher. This demeans the teaching profession. The College of Education, which should be maintaining educational standards and promoting the public appreciation of teaching, is acquiescing in the erosion of both.

Until quite recently in New Zealand there was a consensus that first, numeracy was a basic aim of primary education, and second, a teacher needs to know something in order to teach it. Buzeika' study indicates the extent to which these hitherto fundamentals have been rejected. The downplaying of numeracy is symptomatic of the declining respect for educational content, and the confusion about proper goals for New Zealand education. The above trainee teachers had successfully completed 12 years of school, yet almost half of them did not know *how* to work out these simple everyday problems. What have they learned instead of this fundamental ability?[7]

Tom Nicholson and others have exposed massive illiteracy in significant parts of the school population. Buzeika's results indicate a comparable level of innumeracy in the country. This in itself should be totally unacceptable, but it also has immediate flow-on effects for the level and kind of science that can be taught. Without numeracy, only muck-about science is possible; without basic algebra, or knowledge of graphs, or of equations, students will stay stuck at the level of 'children's science'.

Science literacy cannot be divorced from general literacy. If children cannot read, if they cannot write, if they cannot add up, or do division, or manipulate simple equations, if they are incapable of logical thought, and more interested in 'brain dead' television than learning – then expectations of scientific literacy are misplaced. This is why the New Zealand science situation is so alarming, and why its remediation requires an across-the-board educational response.

CHAPTER 3

VARIETIES OF CONSTRUCTIVISM

Constructivism means different things in different disciplines. First, and most important for this book, there is educational constructivism, which is a many-faceted doctrine, with one commentator identifying at least twenty-one varieties (Good, *et al*., 1993). Second there is constructivism in the philosophy of science that owes a lot to Thomas Kuhn's influential *The Structure of Scientific Revolutions* (Kuhn, 1970). Third, there is constructivism in the sociology of science, a position identified with the Edinburgh 'Strong Programme' in the sociology of scientific knowledge. These constructivist positions are widely held by postmodernists and by some, but by no means all, feminists. The XXVth Nobel Conference, held in 1989, well illustrates the degree to which the traditional Enlightment or modern view has been challenged even in the 'heartland' of science. The letter of invitation to participants recognised that:

> there is an uneasy feeling that ... science , as a unified, universal, objective endeavour, is over ... We have begun to think of science as a more subjective and relativistic project, operating out of and under the influence of social ideologies and attitudes ... This leads to grave epistemological concerns.
>
> (Holton, 1993, p.142)

In order to situate educational constructivism on the intellectual canvas, something needs to be said about the second and third strands of the doctrine.

Constructivism in Philosophy of Science

The clearest contemporary proponent of the second strand is Bas van Fraassen who maintains that:

> Science aims to give us theories which are empirically adequate; and acceptance of a theory involves a belief only that it is empirically adequate. This is the statement of the anti-realist position I advocate; I shall call it *constructive empiricism.*
>
> (Fraassen, 1980, p. 12).

For him:

> To be an empiricist is to withhold belief in anything that goes beyond the actual, observable phenomena, and to recognise no objective modality in nature . . . [it] involves throughout a resolute rejection of the demand for an explanation of the regularities in the observable course of nature, by means of truths concerning a reality beyond what is actual and observable.
>
> (Fraassen, 1980, p. 202)

This version of constructivism, which has roots back through Pierre Duhem (Duhem, 1908/1969), Ernst Mach (Mach 1883/1960), and George Berkeley (Berkeley, 1721/1901) to instrumentalists of ancient Greece. This tradition believes that theoretical constructions, such as magnetic fields or intelligence, are perfectly legitimate in science provided they are not thought to be real, provided they are understood as shorthand ways of referring to compass needles moving, current being induced in moving wires, or constellations of exam scores. Osiander's 1543 preface to Copernicus's *De Revolutions* where he says that the Copernician system is to be understood merely as an aid for convenient astronomical calculations, but not true in reality, is pure instrumental constructivism. There have always been realist opponents to this tradition. [1]

Although Thomas Kuhn is often enough, as we will see in chapter eight, mentioned by educational constructivists, the arguments of his realist opponents are seldom mentioned. It is also important to realise that there have been progressive changes in Kuhn's ideas since the first edition of *The Structure of Scientific Revolutions* (1962). These were announced in the Postscript to the second edition of the book (1970), and in his opening and closing essays in the collection devoted to his work *Criticism and the Growth of Knowledge* (Lakatos and Musgrave, 1970). Kuhn has undoubtedly given joy to relativists and subjectivists, but it is by no means clear that these labels can be applied to him. In the Postscript to the second edition, he says clearly enough that 'scientific development is, like biological, a unidirectional and irreversible process. Later scientific theories are better than earlier ones for solving puzzles in the often quite different environments to which they are applied. That is not a relativist's position ... I am a convinced believer in scientific progress' (Kuhn, 1970, p. 206). The kernel of his idea of paradigm is that of an objective, extra-individual, set of techniques for problem solving that are vouchsafed by a community of scientists, and into which neophyte scientists have to be apprenticed. Admittedly there is more to Kuhn than this, but a great deal of the embellishment has been severely criticised by historians and philosophers of science.

Abner Shimony, a physicist and philosopher, believes that the great value of Kuhn's insights about tacit knowledge, about the importance of history for epistemology, and about the theory dependence of observation has been 'debased by drawing from them relativistic and subjectivistic epistemological conclusions' (Shimony, 1991, p. 96). He believes that the great value of tacit knowledge 'is not its tacitness, but its knowledge' (p. 96); and that 'the appropriate moral to be drawn from scientific revolutions [in mature sciences] is not relativism but a doctrine of successive approximations to the truth' (p. 97). Another critic has remarked that 'The point I have tried to make is not merely that Kuhn's is a view that denies the objectivity and rationality of the scientific enterprise; I have tried to show that the arguments by which Kuhn arrives at his conclusion are unclear and unsatisfactory' (Shapere, 1984, p. 57).

Mere appeals to Kuhn in order to establish constructivist views about the nature of science are not sufficient. Kuhn's theses and arguments are both unclear and contentious. Constructivists in their writings should give some hint of this. They rarely do. Instead statements of the following form are depressingly common in science education literature: 'since Kuhn we know X, Y, or Z', where X, Y, Z might be claims such as: 'science does not seek the truth', or 'truth is a matter of paradigm adopted', or 'knowledge is all relative', or 'truth depends upon your point of view' etc. These assertions assume an agreement with Kuhn that is simply lacking in the professional literature – see for instance the interpretation of Kuhn by Hoyningen-Huene (1993), and the contributions to Gutting (1980) and Lakatos and Musgrave (1970).

Constructivism in the Sociology of Scientific Knowledge

The philosopher and cognitive psychologist, Peter Slezak, says that:

> There could scarcely be a more fundamental contribution to science education than the one offered by constructivist sociological theories, since they purport to overturn the ' very idea' of science as a

> distinctive intellectual enterprise with its special values. If the social constructivist views are right then the goals [of science education] are illusory.
>
> (Slezak, 1994a, p. 291)

For these sociologists there cannot be scientific discovery, only scientific constructions that obtain greater or lesser agreement in the community. As two of the major figures in the field have said of science: ‘each test, laboratory author and discipline strives to establish a world in which its own interpretation is made more likely by virtue of the increasing number of people from whom it extracts compliance’ (Latour and Woolgar, 1986, p. 285). Community agreement or compliance is created largely by non-epistemic factors – group pressure, funding advantages, personality traits, the cultural milieu etc. Evidence and rational argument supposedly play little role in developing scientific consensus, or if they do play a role, they are merely the acceptable face of basically non-epistemic factors.

The strong programme tries to account for the development and change of scientific theories as the causal product of certain social circumstances. Traditional notions of truth, rationality, and individual competence are discounted. The work of Karl Mannheim (1922, 1936) is seminal for constructivist sociology of science. The Edinburgh School gave new life to this tradition with the publication in 1976 of David Bloor’s *Knowledge and Social Imagery* (Bloor, 1976/1991), in the following year Barry Barnes’ *Interests and the Growth of Knowledge* (Barnes, 1977), and in 1979 Bruno Latour and Stephen Woolgar’s *Laboratory Life: The Social Construction of Scientific Facts* (Latour and Woolgar, 1979). In 1982 Barnes and Bloor published a manifesto for the strong programme (Barnes and Bloor, 1982) in which knowledge was stated to be ‘any collectively accepted system of beliefs’. This definition is in contrast to the traditional philosophers’ definition of knowledge as justified true belief. Stephen Shapin (1982) attempted an extensive sociological reconstruction of the history of science in which social factors replaced personal intelligence and evidential considerations as the moving forces behind scientific development and discovery.

The canonical text for the Edinburgh strong programme is *Knowledge and Social Imagery* (Bloor, 1976/1991), which maintains that any adequate sociology of scientific knowledge will adhere to four commitments:

1. *Causality.* It will seek to identify the social, and other causes, that bring about scientific belief, and that cause changes in scientific belief.
2. *Impartiality*. It will treat true and false, rational and irrational beliefs, the same. Both sides of each dichotomy will be subject to sociological explanation.
3. *Symmetry.* The same types of causes will be used to explain successful and unsuccessful science, true and false scientific belief.
4. *Reflexivity*. The patterns of explanation used to explain scientific belief will be used to explain sociology of science.

The truth of a belief, or theory, is not a crucial factor in explaining the adherence of scientists to it; indeed it is not a factor at all, as exactly the same factors are to explain adherence to false beliefs. The nature of the real world has a minor role to play in shaping the growth of science, it is the various and changing commitments held by scientists that shape the growth of science. And these commitments are to be explained in social terms – either *proximal*, as in the immediate working environment of the scientist, or *distal*, as in the culture or milieu of the scientist.

Sociologists of science have been joined by cultural historians of science who ‘feel the need to defenestrate science, or at least take it off its pedestal’ (Pumfrey, *et al*., 1991, p. 3). As with the sociologists, the latter believe that:

> Knowledge is no transcendental force for progress. Historically understood, it is local, it is plural, it embodies interests, it mobilises the claims of groups and classes, and, above all, it is recruited, willy-nilly, on all sides in wars of truth.
>
> (Pumfrey, *et al*., 1991, p. 3)

In common with adherents of the strong programme, cultural historians believe that the development of science cannot be explained in terms of epistemic factors. The growth of Newtonianism, for instance, has to be explained in political, cultural or economic terms. And counterwise, the decline in astrology cannot be explained in terms of its failure to grasp the workings of the world but, as astrology and Newtonianism are epistemically equivalent, its demise has also to be sought in external factors.

Julian Martin, for instance, has written an essay on ‘Natural Philosophy and its Public Concerns’ (in Pumpfrey, *et al*., 1992) saying that ‘historians of science are increasingly deploying the perspectives and techniques of the social historian in explaining their subject matter’ (p. 100), and consequently he sees that it is the ‘vigorous promotion of certain models [of scientific knowledge that] force others to the fringes’ (p. 100). The unstated assumption is that this vigorous promotion is independent of the epistemic worth of the competing models. Thus if more powerful interests, or more capable defenders, got behind, say Aristotelian physics, then it, rather than Newtonianism, would today be taught in universities. For Martin, and other cultural historians, ‘no more than political or economic historian[s] can we appeal to any inherent “rightness” or “wrongness” in particular proposals to explain their success or failure’ (p. 100).

Once truth goes, then the historian’s role is ‘not upon plotting the triumphal progress of truth, but upon interpreting structures of belief’ (Pumfrey, *et al*., 1991, p. 3). This is a clear retreat from the traditional concern with the match or mismatch between belief and its object – that is, whether beliefs are true or false. Cultural historians of science focus upon the structure and dynamics of beliefs without concern to their epistemic adequacy. Thus, for these historians, the Scientific Revolution is not studied as a ‘progressive victory of truth or scientific method’, but rather as a matter of ‘cultural conflicts’ (Pumfrey, *et al*., 1991, p. 3). That something is true and reasonably argued is, for these historians, not an explanation for people’s belief in it.

Paul Forman’s study of the history of physics in the Wiemar Republic is representative of many case studies by sociological constructivists. In accounting for the rise of indeterminacy he says that:

> ... substantive problems in atomic physics played only a secondary role in the genesis of this acausal persuasion, [the] most important factor was the social-intellectual pressure exerted upon the physicists as members of the German academic community [seeking public acceptance].
>
> (Forman, 1977, p. 109)

This, and other such claims, if true, are certainly destructive of traditional ideals of scientific rationality that, among other things, are frequently utilised to justify compulsory science programmes in schools. But one should be cautious about Forman's, and other such claims. The Wiemar Republic was transitory; Copenhagen non-determinant interpretations of quantum mechanics are still with us. Are we really to believe that for the past half century the conceptual scheme of quantum mechanics has been maintained by the memories of the 1920s? Why did not indeterminacy vanish when its social function ceased? Why did the physics community *outside* of Wiemar, often in very stable societies relatively untouched by the Great War, endorse non-determinant interpretations of quantum theory? We know that any number of social taboos function in the manner that Forman is claiming for inderterminacy – they carry on long after their material base has vanished – but to claim that scientific belief in indeterminacy is precisely akin to Jewish avoidance of pork, or Muslims eating with the right hand, stretches credulity.

Clearly there are cultural influences and conflicts in the development of science: this is a truism. The interesting questions, and certainly the educationally valuable questions, emerge when one sees these conflicts as being about truth, and the grasp of realities beyond individuals. But Edinburgh School sociologists of science, and cultural historians of science, rule out the examination of such questions. If truth is ruled out, then the important question of what cultural conditions are conducive to the discovery of truth is likewise ruled out of court. This is surely a distrubing consequence.

These iconoclastic positions have their critics. Some of the better known are Mario Bunge (1991, 1992) who described much of the work in the field as 'a grotesque cartoon of scientific research'; David Stove (1991) who said that the strong programme was a 'stupid and discreditable business', whose authors were 'beneath philosophical notice and unlikely to benefit from it'; Larry Laudan (1981, 1990) who said that the programme's relativism was 'the most prominent and pernicious manifestation of anti-intellectualism in our time'; and Peter Slezak (1989, 1994a,b) who has warned that 'ultimately the intellectual and moral depravity of the sociology of science is of less interest than the broader consequences of these doctrines ... there is a disturbing affinity between such views and those of revisionist historians who would deny the gas chambers of Auschwitz' (Slezak, 1994a, p. 290).

The foregoing authors provide detailed arguments against the strong programme. This is not the place to rehearse them, except to point to one glaring problem that adherents to sociological constructivism face: they cannot reasonably criticise corrupt, but dominant science. We do want to express outrage when results of environmental impact statements are cooked in order to favour some sleazy development, or when drug trials are biased in order to get approval for some doubtful concoction, or when whole research programmes are deformed in favour of some state-sanctioned ideology, such as happened with Lysenkoism in the old U.S.S.R. Science education programmes should cultivate this sense of outrage with the corruption of science. However it is difficult to see the grounds for constructivist's outrage: if science is all construction, and if truth is just what happens to be agreed upon, and if justification is just the obtaining of compliance – then the Stalinists, sleaze merchants, creation scientists, and others, are all doing good science. Hardly a happy conclusion. Outrage requires some normative notion of standards, or ideals, that the subject of outrage violates.

Although Latour and Bloor are quoted by educational constructivists, their critics are rarely mentioned. Students unfortunately are given the impression that the history, philosophy and sociology of science are a closed constructivist shop.

Educational Constructivism

Educational constructivism, borrows elements from philosophical and sociological constructivism, but it has its own independent sources. There are many varieties, from pedagogical to theoretical. In some of its guises it amounts to more of a world view than a specific learning, or pedagogical, or epistemological theory. This is not surprising, because if the epistemological and ontological claims are taken seriously, then major readjustments of standard views about science and life are called for. For instance, one prominent constructivist says that:

> To become a constructivist is to use constructivism as a referent for thoughts and actions. That is to say when thinking or acting, beliefs associated with constructivism assume a higher value than other beliefs. For a variety of reasons the process is not easy.
>
> (Tobin, 1991, p. 1).

Some Early Influences

Constructivism in education has its origins in Piaget's Kantian-influenced learning theory. His early books *The Child's Conception of the World* (1929) and *The Child's Conception of Physical Causality* (1930) emphasised the active role of the learner in assimilating information and accommodating existing beliefs and conceptions to experience. His life-long project of genetic epistemology was designed to answer the question of how much the subject, and how much the object contributed to human knowledge (Piaget, 1970).

Piaget drew attention to the structures of the mind and their maturation as children developed (Piaget, 1964). Stimulation alone meant little to the individual, it was always interpreted in terms of prior experience. Piaget's was a cognitive learning theory in opposition to varieties of behaviourism, informed by Pavlov, Thorndike and Watson, that treated the mind, at best, as a black-box that could be by-passed in theories of learning. The Piagetian investigation of children's views of the natural world was extended when M.E. Oakes published his *Children's Explanations of Natural Phenomena* (Oakes, 1947).

Ernst von Glaserfeld is a prominent educational constructivist who sees his own work as an elaboration of the Piagetian programme. He is the leader of the Radical Constructivist wing, for whom the authentic working out of Piaget's insights 'involves the demolition of our everyday conception of reality and, thus, of everything that is explicitly or implicitly based on naive realism' (Glaserfeld, 1987, p. 96). There is, predictably enough, dispute among Piagetian scholars about von Glasersfeld's claim to be developing Piaget's programme. Jon Ogborn, for instance, comments that: 'It is particularly unfortunate that von Glasersfeld's account of educational constructivism presents itself as a plain exposition of the constructivist thinking of Piaget, whilst actually being a deformation verging on parody of his ideas ... Piaget provides just what the deformed account of his ideas lacks, a means for the world to enter the mind' (Ogborn, 1994, p. 5).

A contemporary of the early Piaget was the Russian linguist and psychologist Lev Vygotsky who extended Marx's anti-essentialist insight that human nature was not transcendent and fixed, but was social and historical. Vygotsky's writings, when translated and published in English (Vygotsky, 1962, 1978, 1979) fed into educational constructivism, giving rise to a variant labelled 'social constructivism' or 'socioculturalism' which sought to rectify the putative individualism of the Piagetian tradition. Vygotsky constantly asserted the Marxist view that 'the social dimension of consciousness is primary in fact and time. The individual dimension of consciousness is derivative and secondary' (Vygotsky 1979, p. 30; in Cobb 1994). Wertsch (1985), Duckworth (1987), Lave (1988), Saxe (1991), and Newman and co-workers (Newman, 1989) are present-day representatives of this social constructivist tradition.

In the mid-1950s George Kelly wrote a book *The Psychology of Personal Constructs* (Kelly 1955) that two decades later contributed to educational constructivism.[2] For Kelly every person constructed the world differently and tested their constructions against experience, 'every man was a scientist'. Two interpreters of Kelly's work for education have said:

> Thus for Kelly the questioning and exploring, revising and replacing, in the light of predictive failure, which is symptomatic of scientific theorising, is precisely what a person does in his attempts to anticipate events. The person can be seen as a scientist constantly experimenting with his definition of existence.
>
> (Pope and Keen, 1981, p. 26)

Kelly's account of our mental life illustrates the strengths and weaknesses of constructivism. The characterisation has a certain seductive, almost Popperian, ring to it – the critical, restless, investigative individual, constantly probing reality and adjusting their beliefs accordingly. However it is not science. Kelly has a flawed Robinson Crusoe characterisation of science. It is individualist to its core. A more accurate view is that scientists' concepts, beliefs and methods come from their initiation into a scientific tradition, that is, from their schooling in science. This involves a huge measure of 'taking on trust'. They do not revise their beliefs in the light of their own experience, they revise them in the light of their experience checked against other's experience, and even then only slowly. In no-one's experience of gases does pressure times volume equal a constant. By definition, no-one's experience reveals the law of inertia, yet these are fundamental laws of science. Andrea Di Sessa remarks on the failure of standard discovery learning are applicable to Kelly's characterisation of scientific investigation. 'It seems', he said, that:

> ... very few subjects, if any, had learned much characteristically Newtonian from dealing with the everyday world ... thought experiments might be more useful than 'playing around'.
>
> (Di Sessa, 1982, p. 62)

This comment is applicable to Kelly's formulation of the 'everyone is a scientist' doctrine (which recurs in the opening pages of *Science in the New Zealand Curriculum*). It is mistakenly individualist and empiricist. It is perhaps noteworthy that Kelly's professional life was spent with schizophrenics. For these unfortunate individuals, truth is what it appears to be, or what it is constructed to be. Kelly's theory may capture their experience of the world, and the dynamics of their mental life, but this is no ground for extrapolating the same process to the dynamics of science.

Contemporary Educational Constructivism

Different strands of constructivism have developed for science, mathematics and humanities education, and there are variations within each strand. Constructivism in science education is a heterogeneous movement. A recent review has identified at least the following varieties: contextual, dialectical, empirical, information-processing, methodological, moderate, Piagetian, post-epistemological, pragmatic, radical, realist, social and socio-historical (Good, Wandersee and St Julien, 1993).

The 1978 Ros Driver and Jack Easley review of literature related to concept development in adolescent science students, is a convenient, if somewhat arbitrary, place to locate the beginning of one strand of constructivism in contemporary science education (Driver and Easley, 1978). This is the 'student misconceptions' or 'alternative frameworks' strand which underpins major research programmes in science education. At Waikato and Monash universities, this strand was called 'children's science'. Two recent anthologies present a range of constructivist research in science education that extends this 'misconceptions' strand whilst nevertheless repudiating the label 'misconceptions' in favour of non-judgemental labels such as 'alternative conceptions' (Tobin, 1993; Fensham, Gunstone and White , 1994).

This conceptual change strand in science education breaks from the Piagetian tradition of constructivism. The Piagetian strand is represented in the work of developmental psychologists such as Michael Shayer and Philip Adey (Shayer and Adey, 1981), who emphasise the 'central processing mechanism of the mind, seen as a gateway which controls all intellectual activity ... this was the nature of the theory established by Jean Piaget through over 40 years of work with children' (Adey, 1992, p. 3). This more orthodox Piagetian strand believes that the 'central processing mechanism of the mind' places limits upon what can be constructed by the mind, and in what order things can be constructed. Philip Adey, and others, believe that the conceptual change research programme (as is found at Waikato) simply lacks any decent psychological theory to inform and interpret its plethora of empirical findings.

However as well as being heterogeneous, constructivism is an expanding doctrine. Constructivism, from its origins in developmental psychology, has spread to encompass many domains of educational inquiry. The range of constructivist concerns can be seen in the subheadings of a recent science education article written by Beverley Bell: 'A constructivist view of learning', 'A constructivist view of curriculum' and 'A constructivist view of curriculum development' (Bell, 1991). In the one article constructivist views on learning theory, epistemology, pedagogy, theory of science and educational theory are elaborated.

Constructivism also has an ethical dimension. A recent paper says 'There is also a sense in which constructivism implies caring – caring for ideas, personal theories, self image, human development, professional esteem, people – it is not a take-it-or-leave-it epistemology' (Watts, 1994, p. 52). An ethical dimension is manifest in the frequency with which notions of emancipation and empowerment occur in constructivist writing. The major New Zealand teacher education programme, directed by Beverley Bell, is described as having 'originated in an emancipatory project of teacher empowerment' (Gilbert, 1993, p. 36). These comments suggest that constructivism is in danger of becoming a form of secular religion, with emancipation and empowerment replacing salvation and grace. It is not clear what is to happen to teachers who do not want to be emancipated in this way.

There is also a political dimension to much constructivist writing. Two constructivist writers say that they are 'committed to the philosophy and principles of composite grades and mixed-ability groupings' (Brass and Duke, 1994, p.100). (One would have thought that constructivist learning theory would have, on efficiency grounds, inclined to graded classes, but this is another matter.) Reinforcing this political side of constructivism, one writer has identified the Progressive Education tradition as constructivist, and the British Plowden Report of the mid-1960s as the embodiment of constructivist school organisation (Hawkins, 1994).

A number of constructivists align themselves with the Critical Theory of Michael Apple, Henry Giroux and Stanley Aronowitz. One Waikato constructivist, as we have seen, says that ‘There are many parallels between the literature on the development of critical pedagogy [and] the literature on constructivist learning’ (Gilbert, 1993, p. 35), because ‘Critical theorists question the value of such concepts as individualism, efficiency, rationality and objectivity, and the forms of curriculum and pedagogy that have developed from these concepts’(Gilbert, 1993, p. 20).

Much is said in the name of constructivism that goes well beyond its original domain of learning theory. These extensions are often not supported with any argument, or with only minimal gestures like ‘since Kuhn ...’ or ‘as critical theory shows ...’. It is assumed that constructivist learning theory is correct, and that it has flow-on effects for epistemology, educational theory, political theory and so on. Unfortunately *non sequitur* argument abounds in constructivist writing. So much so that the suspicion must arise that it is not really *argument* that we are dealing with, or at least not standard old-fashioned *rational* argument. Maybe the constructivist rhetoric needs to be deconstructed (sic) in order to see what it is really about. It would not be the first time, nor the last, that movements make loud laudatory claims about ‘emancipation’, ‘empowerment’, ‘caring’, ‘concern’, ‘development’ – remember the Americans in Vietnam, and the Soviets in East Europe – to deflect analysis and criticism. After all, how can one possibly complain about something that is emancipating, empowering, developing and caring for everyone?

Constructivism at Waikato

Waikato University’s Unit for Science and Mathematics Education Research (subsequently changed to the SMER Centre), was established in 1981 as the country’s first science education research unit. Previously, curriculum and policy development were shared between interested staff in university science faculties, Teachers Colleges, and the Ministry of Education. There was very little science education research conducted in the country.[3] The SMER Centre was the only science education research unit in New Zealand until the establishment in 1992 of the University of Auckland’s chair in science education. For these reasons, Waikato has been synonymous with New Zealand science education research. Since its inception the SMER Centre has developed a significant international reputation; its staff have published scores of books, monographs, and research papers; it has published hundreds of working papers; it has held almost all of the government’s major science education contracts; it has produced scores of PhD students and hundreds of master’s students. Its output has been prodigious, especially given the small core of permanent staff. Yet, almost unique in international terms, nearly all the staff share an adherence to one particular view of science education, the constructivist view. Such unanimity has its obvious strengths in terms of programme coherence and focus, but it also has weaknesses. Enough is written about the former, this book will largely point to weaknesses in the Waikato research programme.

The First Stage (1976-1985)

The late Dr Roger Osborne was appointed to the physics department at Waikato University in the early 1970s. He completed his PhD in 1976 on a model for the teaching of first year university physics, with Peter Freyberg, the founding professor of education, as his supervisor. The thesis stays very close to the ground, or to the blackboard, if one prefers. It says of itself that:

> The research work described in this thesis evaluates the contribution which a systems approach can make to the development of an instructional programme. The thesis investigated is that such an approach can lead directly to a better understanding of the instructional process in a given subject and thus indirectly to more efficient instruction in that area.
>
> (Osborne, 1976, p. ii)

Among its conclusions were that a systems approach to instruction meant that ‘objectives of the course were clarified’, and that there was ‘adequate measurement of the attainment of the course objectives’. Further such an approach ‘emphasised the importance of obtaining useful feedback information from students, so that appropriate changes could be made to instruction and so the effect of these changes could be monitored’ (Osborne, 1976, p. 201). This is all very orthodox and traditional. It is difficult to detect anything of the later generative learning approaches, much less of the full-blown constructivism now associated with Waikato.

Osborne and Freyberg jointly established the Science Education Research Unit at the University of Waikato in 1981. This unit was awarded three major Ministry of Education contracts, spanning the years 1979 to 1984, to study children’s learning of science. The first Learning in Science Project (LISP) ran from 1979 to 1981 was focused on the processes and conditions of science learning in Forms 1-4. The second LISP project ran from 1982 to 1984 and focused on learning in the Primary school years. The third project ran from 1985 to 1988 and focused on learning of the Energy concept and the fourth concerned with Teacher Development, commenced in 1988 and concluded in 1993 (Bell 1993). The seeds of New Zealand constructivism were sown during the first two LISP projects, the plant blossomed from the mid-1980s.

The Project Co-ordinator for the first LISP project was Ross Tasker, then a science teacher, and until recently a co-ordinator in the Curriculum and Contract Management Division of the Ministry of Education who had responsibility for the letting and monitoring of Ministry science education contracts. One of the team leaders in the project was Beverley Bell, a former science teacher and curriculum officer with the Department of Education, now a senior lecturer at Waikato and director of the SMER Centre. Beverley Bell’s DPhil was supervised by Roger Osborne, Peter Freyberg, and for a time, Tom Nicholson, and was awarded in 1984 on the topic of ‘The Role of Existing Knowledge in Reading Comprehension and Conceptual Change in Science Education’.

The first two LISP projects were published by Waikato University and distributed by the Department of Education. The projects generated an enormous number of minor, and a good many major, research reports. The public and international face of these projects was the previously mentioned Roger Osborne and Peter Freyberg book, *Learning in Science: The Implications of Children’s Science* published in 1985, and subsequently reprinted numerous times. For a decade it has been the canonical book for New Zealand science education.

The book focuses on science classroom events and dynamics, the investigation of children's learning of specific chemical, biological and physical matters, the effect of language on learning, the role of the teacher in learning, and the formulation of a model for good teaching. It does devote one of its 200 pages to the Role of Science in the Curriculum, but that is about as high-flying and removed from the classroom as the book gets. It is an eminently practical, accessible, descriptive, and non-theoretical book. The Preface of the book summarises the research findings of the two LISP projects, and the then burgeoning Children's Ideas in Science research from other parts of the world, as being:

> ... children bring to science lessons views of the world and meanings for words which have significant impact on their learning. As a consequence children's ideas are influenced in unanticipated ways by science teaching. (Osborne and Freyberg, 1985, p. 1)

This is hardly a revolutionary finding, but it is nevertheless important. The Preface also announces the book's low-key aspirations as being to:

> ... explore these findings, analyse their significance for the teaching/learning process, and suggest both general and specific solutions to problems they identify for both learner and teacher.
>
> (Osborne and Freyberg, 1985, p. 1)

Learning in Science is about teaching and learning in science classrooms. It is written by science teachers, for science teachers and trainee science teachers. There is almost nothing in it about larger issues such as the role of science in the curriculum, the content of science programmes, or curriculum matters more generally. It does not deal with educational theory and philosophy, or the sociology and politics of schooling, much less human liberation and emancipation. Consideration of these wider issues come later when the initial LISP project changes into a constructivist package-deal that generates theories of science, schooling, and education. There are however two throw-away epistemological lines in the book that have ever since haunted New Zealand science education. In the opening and closing lines of the book, the authors, without supporting argument or references, assert first, that the aim of science is to make sense of the world, and second, that knowledge is a personal construction. Slight though these ideas are at their source, they have cast an incredible and disorientating shadow over subsequent New Zealand science education. Or, to change metaphors, they were the pebbles that precipitated a constructivist avalanche. These two epistemological doctrines, *making sense* and *personalism*, so casually introduced, have been responsible for the misdirection of science education research, curricula, teacher education and policy.

Science as a way of making sense of the world

The 1985 book commences with the statement that:

> Young children and scientists have much in common. Both are interested in a wide variety of objects and events in the world around them. Both are interested in, and attempt to make sense of, how and why things behave as they do.

(Osborne and Freyberg, 1985, p. 1)

This is the first statement that I can find of the *Science-is-a-Way-of-Making-Sense-of-the-World* doctrine which flows through official New Zealand science education pronouncements from the mid-1980s to the present. In the 1989 *Draft Forms 1-5 Science Syllabus* it occurs on the second page as the statement that:

> Science is about people exploring and investigating their biological, physical, and technical worlds, and making sense of them in logical and creative ways.
>
> (Ministry of Education, 1989, p. 5)

The 1993 final *Science in the New Zealand Curriculum* document opens with the very same sentence:

> Science involves people investigating the living, physical, material, and technological components of their environment and making sense of them in logical and creative ways.
>
> (Ministry of Education, 1993, p. 7)

In the Waikato group's contribution to the 1992 Monash University seminar on constructivism, we again read that:

> ... the learner needs to appreciate that science has been *constructed by people* as a way of making better sense of the world. This has obvious implications for science teaching and learning.
>
> (Carr, *et al*., 1994, p. 155)

If correct, this doctrine certainly does have implications for science teaching, learning and assessment. For instance, making sense of the world will replace gaining knowledge of the world in curriculum objectives. This has already been done in the *Science in the New Zealand Curriculum* document, where 'Making Sense of the Living World', 'Making Sense of Planet Earth and Beyond' etc. are the subject matter headings! One wonders what is so wrong with good, old-fashioned 'Learning About Planet Earth' or 'Learning About the Living World'? Nothing it would seem, except that such forthright statements jar with constructivist pet doctrine. And of course there is a well-worn slippery slope between science's alleged goal of making sense of the world, and making sense of *experience* of the world. This is a Kantian slope down which many constructivists, and others, slide in their journey to complete relativism, solipsism and scepticism. The very intellectual disorders that a science education should counteract.

I believe that this *making sense* view is a fundamentally erroneous and dangerous conception of the nature and goals of science: science does not strive to make sense of the world, it strives to find out the truth about the world, which may or may not make sense. Making sense is a bonus, it is not the objective of science. For two thousand years the architectonic system of Aristotelianism made wonderful sense of the world and of human experience. It could not be faulted on these grounds. Nevertheless it was just wrong. Galileo and others did not argue that Aristotelianism failed to make sense, they argued that the world was not like the Aristotelians believed it to be. Scientific truths when found, normally do not make sense, rather they require the overturn and reconstitution of common sense. As many people have observed, if it makes sense it is probably not scientific. Lewis Wolpert has recently, and clearly, argued this position. He states that ‘Scientific ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience’ (Wolpert, 1992, p. xi).

A noteworthy feature of sensism in the Waikato publications is that it is completely unsupported: from its first appearance in 1985 to its enshrinement in the *Science in the New Zealand Curriculum* of 1993 it is not buttressed by any supporting argument. Not a single piece of philosophical or historical literature is cited to justify this contentious – to put it mildly – viewpoint. This is a peculiar style of academic argument where evidence is replaced by assertion.[4]

Subjectivism: knowledge as a personal construction

The second epistemological seed casually planted in the closing lines of the Osborne and Freyberg book is *subjectivism*. They state that:

> Knowledge is acquired not by the internalisation of some outside given but is constructed from within.
>
> (Osborne and Freyberg, 1985, p. 82)

This idea has reverberated through all subsequent New Zealand science education pronouncements. It has become the *credo* of Waikato science and mathematics education research. Beverley Bell repeated the claim the year after the Osborne and Freyberg book was published, saying:

> Knowledge is the personal construction of an individual and does not exist externally to be transmitted.
>
> (Bell, 1986, p. 6)

As with sensism, subjectivism is contentious at best, and plain silly at worst. It is ridiculous to assert that people construct knowledge of the world from within. This claim ignores the difference between belief and knowledge; the public nature of the concepts in which knowledge claims are couched; the extra-individual nature of the criteria for determining knowledge; and the irredeemably social nature of science. The silly *epistemological* claim hides behind a perfectly ordinary *psychological* claim that individuals need to exercise mental abilities when they develop *beliefs*. No one has ever suggested that a person’s thinking can be done by someone else. These subjectivist faults were mentioned at the outset of this book and will be elaborated later, but the philosopher of education, Richard Peters, has stated the crux of my objections to subjectivism:

> Reasoning in general ... does not represent the flowering of an inner potentiality in the individual that is simply encouraged by child-growers. It is basically a public inheritance ... It is public not just in the sense that its vehicle is language ... but in the further sense that, even when it takes place in the individual’s head, it is an internalisation of public procedures.
>
> (Peters, 1975, p. 101)

In summary, the first period of Waikato constructivism was characterised by an enormous amount of research, often in collaboration with British, American and Australian researchers, on what Roger Osborne dubbed ‘children’s science’.[5] The research and the publications were classroom orientated and fairly modest in their claims.[6] However there were two philosophical seeds planted which confound the view that philosophy is harmless: the doctrines of sensism and subjectivism were adopted during this first period, and have remained the guiding, or better, misguiding, principles of most subsequent research from the SMER Centre.

The Second Phase (1985-1993)

From the mid-1980s, publications at Waikato begin to move beyond straightforward studies of children’s learning to wider issues about the educational and social context of science learning and teaching. This phase concludes with the publication in 1993 of the fourth LISP project, *Teacher Development* (Bell, 1993).

In the mid-1980s an important connection was established between Waikato and Leeds universities. Leeds was, and still is, one of the world’s leading centres of constructivist thinking and writing. Beverley Bell from Waikato was employed as a Research Fellow at the University of Leeds in the period 1983-85, and was coordinator of the children’s Learning in Science Project (CLIS). Subsequently Beverley Bell and Rosalind Driver have been back and forth between Leeds and Waikato, and have jointly published a number of research articles (e.g. Driver and Bell, 1986).

The generative learning model

The LISP projects adopted the generative-learning form of psychological constructivism developed by Mel Wittrock, an American researcher of children’s reading (Wittrock, 1974). Roger Osborne took a sabbatical leave with Wittrock at the University of California in Los Angeles in the early 1980s. Their collaboration was expressed in their very influential 1985 joint article titled ‘The Generative Learning Model and Its Implications for Learning Science’ (Osborne and Wittrock, 1985).

This Osborne and Wittrock article exemplifies the claim, that I have argued elsewhere, that constructivism is basically, and at best, a warmed up version of old-style empiricism (Matthews, 1992b, 1993, 1994, chap. 7). Osborne and Wittrock say (pp. 64-65) that the key postulates of the generative learning model include:

- The learner’s existing ideas influence what use is made of the senses and in this way the brain can be said to actively select sensory input.
- The learner’s existing ideas will influence what sensory input is attended to and what is ignored.
- The input attended to by the learner has no inherent meaning.

And they proceed to discuss constructivist teaching in terms of ‘sensory input’ provided by the teacher. They acknowledge that the construction or generation of complex meanings is not straight-forward, this has to be done by the students ‘producing their own sensory inputs’ – tables, diagrams, flow charts etc. Thus all learners are awash in a sea of meaningless sensations that they then aggregate and confer meaning on. It is claimed that the science classroom is a particularly appropriate site for testing the generative learning model because:

> The sensory input can be clearly specified (e.g. reading a scientific text), or consist of a full range of sensory input (e.g. the science laboratory equipment), depending on the nature of the particular research study.
>
> (p. 80)

Whether the sensory input involved in reading a scientific text can be specified at all, let alone clearly specified, is a matter that need not be examined here. What is noteworthy is the claim that texts have no meaning: the meaning of a text is what you make of it. This is very postmodern, but also very dubious: the act of interpretation depends upon there being something with meaning to interpret. There may be various interpretations of a text, but if there is no meaning, then there is simply nothing to interpret. You may be responding to something – a rock, a tree, marks on a page, the sunset – but you are not interpreting these unless they have meaning in the first place. The act of interpretation also implies the possibility of misinterpretation – something that most postmodernists in principle deny.

Wittrock and Osborne are on the post-modernist side of a major battle in contemporary literary studies over the existence of meaning in texts. Roland Barthes, a standard-bearer for post-modernism, writes:

> We now know that a text is not a line of words releasing a single 'theological' meaning (the 'message' of the Author-God) but a multi-dimensional space in which a variety of writings, none of them original, blend and clash. The text is a tissue of quotations drawn from the innumerable centres of culture.
>
> (Tallis, 1988, p. 72)

Barthes takes the short step from eliminating meaning (albeit the strawman 'single theological' meaning) from texts to eliminating all authors (not just his rhetorical God-Author) from texts. He says:

> ... a text is made of multiple writings ... but there is one place where this multiplicity if focused and that place is the reader, not, as was hitherto said, the author. The reader is the space on which all the quotations that make up a writing are inscribed without any of them being lost; a text's unity lies not in its origin but in its destination.
>
> (Tallis, 1988, p. 75)

Barthes has not yet appeared in main-stream science education writing, but presumably he is waiting to be discovered by those who, having adopted the Wittrock and Osborne line, seek some more sophisticated justification for it.

Contrary to Osborne and Wittrock, the statement 'a body only accelerates when it is subject to a net force' has meaning. It is not a mere collection of marks on a page that are devoid of meaning. The meaning of the sentence derives from the system of mechanics in which it originates. People may not understand its meaning, or they may misinterpret its meaning, but to deny that the statement has meaning verges on the bizarre. Making these meanings known and intelligible to pupils, by interesting and engaging pedagogy, is the craft and vocation of a science teacher. Wittrock had in 1972 said that educational psychologists should pay more attention to the 'rich subject matter' of philosophers, and that 'we can learn more about education by relating psychology and philosophy to each other' (Kneller, 1994, p. 103). One wishes that he had followed more of his own advice.

Osborne's collaboration with Wittrock was apparent in the Osborne and Freyberg 1985 book. There Wittrock's constructivism is endorsed in these terms:

> Wittrock's ... view of learning with understanding focuses on the proposition that learners must themselves actively *construct*, or *generate* meaning from sensory input; for example, sights, sounds, smell and so on. No one can do it for them. ... Piaget, too, considered that knowledge is *constructed* by the individual as he or she acts on objects and people and tries to make sense of it all.
>
> (Osborne and Freyberg, 1985, p. 82)

Osborne and Freyberg conclude this endorsement with the statement of subjectivism previously mentioned:

> Knowledge is acquired not by the internalisation of some outside given but is constructed from within.
>
> (Osborne and Freyberg, 1985, p. 82)

These remarks mirror the claim of the leading radical constructivist, Ernst von Glasersfeld, that:

> ... knowledge is the result of an individual subject's constructive activity, not a commodity that somehow resides outside the knower and can be conveyed or instilled by diligent perception or linguistic communication.
>
> (Glasersfeld, 1990, p. 37)

They have been repeated by Rosalind Driver and her Leeds colleagues who say that:

> The core commitment of a constructivist position, that knowledge is not transmitted directly from one knower to another, but is actively built up by the learner, is shared by a wide range of different research traditions relating to science education.
>
> (Driver *et al*., 1994, p. 5)

This principle of incommunicability informs the whole constructivist pedagogical edifice, and is currently working itself out in unforeseen ways in New Zealand: teacher demonstration benches are being removed from school science laboratories, and gas and water services are not being connected to teachers' benches in new laboratories. Even front podiums are being removed from some lecture rooms in Colleges of Education. Classroom geography is meant to reflect underlying epistemology.

Contentious educational theory

I said at the outset that whilst becoming the official line in New Zealand science education, constructivism has transformed from a relatively harmless, if debatable, theory about how children learn science, to an over-arching theory of knowledge (epistemology), of curriculum, of teaching, of teacher development, and of education. The opening pages of the recently concluded three-year, Waikato conducted, Ministry of Education funded, LISP project, *Teacher Development,* is quite explicit about the overhaul of educational practice and thinking that constructivism requires:

> In taking into account the findings of the Learning in Science Projects [LISP], most teachers are challenged to not only change their teaching activities, but to change their implicit theories of students, schools, how children learn, the nature of knowing and knowledge, and the implications of these for teaching.
>
> (Bell, 1993, p. 4)

New Zealand constructivism is not just about how children learn science. It promotes a new and all encompassing theory of education and teaching, the evaluation of which is vital to present education and to the future of New Zealand society.

Just what this new constructivist and critical vision of education is, becomes clear in the 1993 *Teacher Development* document. Some of the ideas concerning a theory of education and a theory of teaching that were suggested during the earlier LISP projects are worked out. The theory of education adopted is, not surprisingly, Critical Theory; which the report associates with the work of the Americans Michael Apple, Stanley Aronowitz, and Henry Giroux. We are told that in critical theory:

> The relationships between teacher development, schooling and the rest of society are emphasised. An important part of the critical perspective is the notion of teacher empowerment.
>
> (Gilbert, 1993, p. 21)

And are reminded that:

> The Learning in Science Project (Teacher Development) originated in an emancipatory project of teacher empowerment.
>
> (Gilbert, 1993, p. 36)

As is characteristic of nearly all the LISP work, there is no argument for the endorsement of Critical Theory. The views are simply stated, and it is assumed that this constitutes an argument. Certainly no opponents of Critical Theory are mentioned, another unfortunate feature of the LISP projects. Henry Giroux's work has been soundly criticised. Francis Schrag's reply to one of Giroux's articles on 'Citizenship, Public Philosophy, and the Struggle for Democracy', gives some flavour of the criticism, and of Giroux's writing style. Schrag focuses on a matter that has been raised throughout this book: the abandonment of clear writing and expression in educational debate.

> The article [Giroux's] shows respect neither for logic nor the English language, nor for the cause it avows, democracy. Consider this sentence:
>
>> In this case, the notion of voice is developed around a politics of difference and community that is not rooted in simply a celebration of plurality, but rather in a particular form of human community that encourages and dignifies plurality as part of an ongoing effort to develop social relations in which all voices in their differences become unified in their efforts to identify and recall moments of human suffering and the need to overcome the conditions that perpetuate such suffering.
>
> Here we have not only Giroux's inability to stop a sentence while he still remembers what the subject is, but a nice example of the evasiveness characteristic of ... him.
>
> (Schrag, 1988, p. 143)

The sentence of Giroux's that Schrag quotes is, unfortunately, representative of much postmodernist, supposedly critical, educational writing – or *educobabble* as it is disparagingly referred to. The ability to write clearly, and to express an opinion in an intelligible manner, should be one of the basic outcomes of education. If that is not achieved, then just about all else is lost. But perhaps if all meaning is in the eye of the beholder, then the old-fashioned requirement of writing what you mean, and meaning what you write, is otiose. If the *nothing has meaning* doctrine is taken literally, then a teacher may as well just stand at the front of the room and make noise: noise and intelligent exposition are, supposedly, equally meaningful (or meaningless). My claim has been that constructivism's emphasis on 'meaning being in the eye of the beholder', has legitimated sloppy writing, and has undermined one of the major purposes of education – having students recognise the importance of clear and coherent expression, and giving them competence in such.

Science teachers can contribute to the development of this basic competence. It is not just the provence of English teachers. Clive Sutton, a British science educator sympathetic to constructivism, has recently published a book, *Words, Science and Learning* (Sutton 1992), which shows how this can be done, and argues why it should be. He says:

> it seems increasingly clear that practical experience of itself does not bring about learning until it is animated by ideas, and these ideas are carried in words. For new experience to be properly linked in with a learner's thought, more attention will have to be paid to words and what is done with them. That includes the pupil's own words, the teacher's words, and the words of those who first created the ideas.
>
> (Sutton, 1992, p. 4)

There is a major educational issue at stake in the debate between, on the one hand, Schrag and others (myself included) and, on the other, Giroux and others (including many constructivists). The issue is the role of language in discourse and argument, and ultimately the means by which different views are appraised and resolved. Giroux seems to recognise this in his reply to Schrag.

> Schrag's demand for definitions and simplicity signifies a massive failure of political and theoretical nerve. His discourse vehemently dissociates knowledge and language from power and ends up reinforcing the dominant ideological practice of emphasizing style and technique over scholarship and

> critical exchange as the basis of academic criticism. ... The point of course is that one's voice and language as a writer and educator must be grounded in a political project capable of exercising a socially relevant criticism aimed at extending those human possibilities that contribute to democratic forms of public life. ... [Schrag's] is the language of the apologist and the hegemonic intellectual, a language incapable of advancing constructive and compassionate dialogue.
>
> (Giroux, 1988, p.145)

It is not entirely clear what Giroux is saying, but on one reading of it, he is at odds with George Orwell who observes:

> [language] becomes ugly and inaccurate because our thoughts are foolish, but the slovenliness of our language makes it easier for us to have foolish thoughts. ... to think clearly is a necessary first step towards political regeneration: so that the fight against bad English is not frivolous and is not the exclusive concern of professional writers.
>
> (Orwell, 1945, in Locke *et al*., 1962, p.126)

If, as some of the Waikato group advocate, Giroux's version of postmodern, critical education theory, is to guide New Zealand education, then at least its critics – both from the Left and the Right – should be mentioned.

There is an enormous body of scholarly literature on the aims and purposes of education. This is the subject matter of philosophy of education. However New Zealand has never employed a philosopher of education in any of its Colleges of Education. Thus science teachers, and others, do not have the training to appreciate the context of, and seriously appraise, modish educational ideas. They are easier prey for literary, pedagogical and philosophical fads, than otherwise might be the case. Of course only a completely closed mind is fully immune from passing fads, but a little traditional philosophy does help.

Nothing is more useful to teachers than a good philosophy of education. During the past decade there has been a philosophical turn in science education. The period has witnessed an unprecedented concern among science educators with epistemological questions, and relatedly, with questions about the nature of science. In addition science educators have been concerned with questions about ethics (animal experimentation, conservation issues, genetic engineering), politics (science for all or professional science for elites, and STS topics such as environmental protection, nuclear energy, sustainable development), and educational foundations (why teach science? should science be compulsory and for how long? is there a difference between education in science and training in science? should science education serve educational, academic or societal purposes? etc.). Answering these questions requires rudimentary philosophical skills and information that are seldom provided in New Zealand teacher education programmes. Importantly, trainee teachers are not given the intellectual wherewithal to appraise constructivist educational and philosophical claims. On the contrary, they are frequently urged to simply repeat them mantra-like.

CHAPTER 4

CONSTRUCTIVISM: THE GOOD AND THE BAD

Constructivism clearly has useful and insightful philosophical and educational elements. If it had no positive aspects its widespread adoption would be a complete mystery. My general claim is that what is good in constructivism is not novel, and what is novel in constructivism, is bad.

Positive Features of Constructivism

Thomas Kuhn's constructivism has certainly done a service to our understanding of science by popularising some important ideas that were previously hidden in the scholarly literature. Scholars are now more sensitive to the historical dimensions of science, and of cognition more generally. They are sensitive to the effect of General Conceptual Schemes (Harré, 1964) or Scientific Themata (Holton, 1988) on the explanatory framework of science, to the influence of the social, economic and cultural milieu on the pursuit of science, and more generally to the interaction of science with philosophy and values (Gjertsen, 1989). These aspects of science had been recognised before Kuhn – think of Mach (1883/1960) on the historicity of cognition, Bernal (1939) on social determinants of scientific development, Randall (1962) on the interaction of science with philosophy, Collingwood (1945) on the untestable metaphysical presuppositions of science – but they had been ignored by the long-dominant, logical-empiricist philosophers of science. One might say that the latter looked at the scientific skeleton, not the body. But none of these Kuhnian advances mean, to follow through the metaphor, that the body does not have a skeleton. Realism, rationality and truth are certainly more complex matters than many had hitherto thought. To be aware of this is a significant gain, but the extremes of constructivism are simply not warranted. Jerry Fodor has nicely remarked on this philosophical tendency to 'promote cures for which there is no adequate disease':

> It is a curiosity of the philosophical temperament, this passion for radical solutions. Do you feel a little twinge in your epistemology? Absolute scepticism is the thing to try. Has the logic of confirmation got you down? Probably physics is a fiction. Worried about individual objects? Don't let anything in but sets. Nobody has yet suggested that the way out of the Liar Paradox is to give up talking, but I expect it is only a matter of time. Apparently the rule is: if aspirin doesn't work, try cutting off your head.
>
> (In Slezak, 1994b, p. 330)

Likewise parts of educational constructivist doctrine and practice are reasonable and worthwhile. It is these sensible parts that perhaps account for the widespread acceptance of constructivism by educators.

Find out what Pupils Think

Constructivists say that teaching is done better if teachers first ascertain what students already know or think about a subject. David Ausubel's dictum – 'The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly' (Ausubel, 1968, p. vi) – was introduced to constructivist research by Joseph Novak in his 1977 book *A Theory of Education*, and has become the constructivist *leitmotif*.

I have no argument with Ausubel's dictum, and it is worth repeating. However teachers need not have waited for Ausubel to learn this. Most intelligent teachers begin by asking what a pupil or class know about the topic to be taught, and then following up the answers. It has been a common idea since at least as far back as the fourth century B.C. Ascertaining the ideas of the audience was Socrates first step in his *Dialogues*: he asks the audience to tell him what they think virtue is, what they think good government is, what they think knowledge is, and so on. They make their replies, and then Socrates gets them to examine these for their coherence, their undesirable consequences etc. Having produced uncertainty in their minds, Socrates leads them on to new ideas.

Perhaps one of the most famous teaching episodes of all time is Socrates teaching Pythagoras' theorem to the slave boy in the *Meno*. Socrates asks the slave boy how he would make a square that was double the area of an initial square. The boy replies that he would double the length of the side. Thus begins a wonderful demonstration of the Socratic Method, a demonstration that has, over the subsequent centuries, been held up as an exemplary model of good teaching – as it was, for instance, by Montaigne is his *Essays* of 1580.

But even this first sensible idea in constructivism needs to be nuanced. Socrates and Montaigne were talking of tutors who taught individual pupils. Their tutors never faced or even contemplated classes of 30 adolescents, a fixed timetable, a set curriculum, bursary exams, the spectre of youth unemployment, the competition of video games and television, and all the other material and cultural constraints of the modern school. They had no conception of a university where the Biology One class might have 1000 students, each with their own interests and competencies.

Further, and more importantly, constructivists constantly say that teaching has to be *confined* to what pupils already have some conceptions of. Teachers are told to ascertain student ideas and build upon them, without this foundation it is maintained that there cannot be effective teaching. This is sensible in fields where students have some ideas, but in many cases students do not have ideas. The very business of education is to expand the mind, to liberate children from the confines of their home and culture, to introduce them to new problems, competences and ways of thinking. Overstating the Socrates, Montaigne, Ausubel tradition results in an insular and parochial education: if you know nothing about a field, then you cannot be taught anything of it.

Students, like most of us, know nothing of most other cultures, or most other periods of history. We do not have preconceptions, we need to be told – either by teachers or books or some other way – what other cultures and historical periods were like. Most students will have no knowledge of the life, times and achievements of Isaac Newton, or of any other figure in the history of science; they will know nothing about electrons or atoms; they will have no opinions about tectonic plates; they will have no conceptions, mis- or otherwise, about gravitational attraction. Good teachers will given them this knowledge – by lessons, talks, projects, essays, or historical re-enactments. The constructivist principle that teachers have to build on *existing* knowledge, results in a very thin building.

Children's ideas arise from three sources: their direct sensory experience of the world, their participation in everyday social life with its conversations and entertainments, and their formal schooling. Direct experience contributes a very limited amount to the development of scientific thought – if direct experience contributed much, science would have arisen long before it did, and would have been found in all cultures, not just in the West.

Participation in everyday life, the lifeworld of the phenomenologists, contributes not much more to the development of scientific thinking, and perhaps even less. The average American 18-year-old has watched 20,000 hours of television, with a few thousand of these being before he or she has ever seen a school teacher (Hamburg, 1992). New Zealand has the dubious distinction of getting the silver medal in the international television-watching stakes: 14 per cent of New Zealand nine-year-olds spend more than five hours a day watching television (Chamberlain, 1993, p. 76). And as a good deal of this television has aptly been called ‘brain dead’, the effects on children, and ultimately on New Zealand culture, are depressing. Neil Postman, in his critique of television culture, has warned that:

> When a population becomes distracted by trivia, when cultural life is redefined as a perpetual round of entertainments, when serious public conversation becomes a form of baby-talk, when, in short, a people become an audience and their public business a vaudeville act, then a nation finds itself at risk; culture-death is a clear possibility.
>
> (Postman, 1985, p. 161)

Constructivists have labelled children’s ideas about nature as ‘Children’s Science’. So we have articles titled, ‘Children’s Science and its Consequences for Teaching’ (Gilbert, Osborne and Frensham, 1982). This at the one time vastly overestimates the coherence and seriousness of children’s ideas, and dramatically underestimates the cognitive achievement of science. Ideas so incoherent, and easily come by, ought not be described as ‘science’. It is better to call them simply ‘Children’s ideas’.

Teach for Understanding

Constructivists stress that we should be teaching for understanding of subject matter, not just rote learning. Again there can be no argument with this. However, once more teachers did not need to await constructivism for this enlightenment. Plato in the fourth century B.C. distinguished between opinion and knowledge. Knowledge was true opinion based on good reasons. Plato said that a knowledgeable guide was not one who just gets you to the correct destination, but one who knew why he was taking certain routes, and would have been able to take others if difficulties arose.

The medieval philosophers distinguished between knowledge of the fact, and knowledge of the reasoned fact, with the latter preferred. The much-maligned scholastics, with their method of proof and refutation, and their sense of a hierarchy of disciplines, strove for deep understanding of their subject matter. They thought, for instance, that if a proper understanding of motion was pursued, it would lead to belief in God.[1]

The British philosopher of education, Richard Peters, placed great stress on understanding in education, saying that:

> Teaching is a complex activity which unites together processes, such as instructing and training, by the overall intention of getting pupils not only to acquire knowledge, skills, and modes of conduct, but to

> acquire them in a manner which involves understanding and an evaluation of the rationale underlying them.
>
> (Peters, 1966, p. 40)

Teaching for understanding has been part of the liberal tradition in education ever since Plato.[2] It is true that many science programmes, with their encyclopedic coverage, have not cultivated understanding, and some assessment practices in science have rewarded rote learning. The following comment by an Australian trainee teacher on her high school mathematics experience is sobering, and unfortunately too common:

> There are various times in my high school years where understanding (or lack of it) remains memorable for me. In my maths class, I would often approach my teacher during her question time in order to ask why you did a certain step in an equation a certain way. I never got an explanation out of her in the five years I was unlucky to have her, as she merely used to say 'you should know why, Amanda'.
>
> In years 11 and 12, I was attempting to struggle with Trigonometry (as I was far from mastering it). My level of understanding of the subject was enough only to complete a few problems before I forgot the reasons why you did the equation a certain way and thus, had to consult my textbook ... my understanding of the subject was purely superficial.
>
> Thus, it can be seen that as a teacher, it is imperative that the student's level of understanding be fostered to achieve something more than a superficial knowledge base. Understanding enables learning ...
>
> (UNSW, 1994)

Constructivists do a service in pointing to the deficiencies of such teaching, but non-constructivists have been doing the same for a very long time. Good traditional educators, who following Plato are concerned to foster pupil understanding, are as appalled by Amanda's school experience as any constructivist is.

A caveat needs to be entered here. The medievals preferred knowledge of the reasoned fact, but they knew that it followed knowledge of the fact. Without knowledge of the fact, knowledge of the reasoned fact was impossible. So too in modern science education: we want understanding, but first children need the facts or problems that they will seek to understand. Often this understanding comes on an instalment plan. Hegel said that philosophy, like the Owl of Mineva, takes wing only at dusk, understanding may not have to wait until dusk, but sometimes it has to wait at least until lunchtime, and until a lot of plain ordinary factual information has been absorbed.

In traditional science education, the curriculum dictates the subject matter to be learned (geology, chemistry, photosynthesis, mechanics and so on), and teachers use their subject matter knowledge and their experience, to present this content to students in a way that students can understand and be interested in. The U.S. educator, Lee Shulman, in writing on the central task of a teacher, asks about the missing paradigm, the command of subject matter, and the ability to make it intelligible to students. For Shulman:

> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice.
>
> (Shulman, 1986, p. 9)

As any teacher knows, this is not an easy task. And it is a task receiving less and less public support, as education and the teaching profession are devalued. However constructivists are adding to the problems, first by undermining the epistemic standing of science – and thus children's motivation to learn it – and, secondly, by deprecating the conceptual nature of understanding – and thus the organisation and structure that is required in teaching and learning. To understand propositions about the minerals in basalt, you need the conceptual context of geology. This is a context that makes reference to types of magma, rates and places of cooling, orders of crystallisation and so on. All of this takes time and attention.

Active Learning

Constructivists say that children should be active in their learning. They should be questioned, and encouraged to question each other and the teacher. Again there is not much to argue about here. No one has ever thought that children's thinking could be done by somebody else, or that they could learn whilst asleep or whilst looking out the window day-dreaming during class. Engagement, thinking, activity, debate, questions, attention are all part of most people's idea of teaching and learning, certainly most liberal ideas. This finding is no novel intellectual breakthrough. However educationally useful questioning depends upon a grasp of subject matter, and rules of evidence etc. In most fields a degree of straight-out learning is necessary before serious questioning is possible.

Again there is a caveat even on this simple point of questioning. Many children and many cultures learn quite well without obvious questioning. I imagine this is the case for nearly all traditional societies. Muslim children learn the Koran quite satisfactorily by repetition. Australian Aboriginal education proceeds effectively by observation and practice, with very little explanation. In traditional Papua-New Guinea societies it is not only bad form to question a teacher, it is also insulting for a teacher to question a pupil. This is seen as shaming the student, as isolating him or her. In most Asian societies it is disrespectful for a student to question the teacher, and students who talk too much, or ask questions are seen as show-offs. Nevertheless Asians learn science very well. (Perhaps it is because teachers are respected, well paid, and education is valued. In Singapore no one teaches school physics without an honours degree in physics.)

In New Zealand there is a good deal of anecodotal evidence to suggest that Pacific Island and Maori children do not respond to open classrooms and their constructivist-inspired climate of debate (unfortunately hard evidence, one way or the other, seems not to have been collected). Australian studies cited in chapter two, show that reading acquisition by children from deprived homes is directly related to the degree of structure in their teaching: phonics beats whole language teaching everytime. In the U.S.A. it is well established that the more traditional and conservative the school, the better will poor children perform on academic tests. Rudolph Flesch had pointed to this in his polemical 1955 best-seller critique of whole-word reading instruction. There he said:

> I say, therefore, that the word method is gradually destroying democracy in this country; it returns to the upper middle class the privileges that public education was supposed to distribute evenly among the people.
>
> (Flesch 1955, p. 132)

Thus the constructivist stress on questioning, on problematising the subject matter as it is known, is a culturally specific educational injunction. It can be deleterious to education, to say nothing of being politically incorrect, when generalised from middle-class cultures to others.

Critiques of Educational Constructivism

Although constructivism in philosophy of science and in sociology of science has been hotly debated and criticised, there has been nothing like the same level of debate about educational constructivism. As Russell Yeany said, 'there is a lack of polarised debate'. Among the few critical writers have been Kenneth Strike (Strike, 1987), Jeremy Kilpatrick (Kilpatrick, 1987), Joce Jesson (1991), Wallis Suchting (Suchting, 1992), myself (Matthews, 1992, 1993, 1994 chap. 7), and participants in a King's College, London, seminar held in 1992 (Black and Lucas, 1994). Yeany's remarks were made of the U.S., but they are even more applicable to New Zealand where, since the early 1980s, the science education community has wrapped itself in the constructivist cloak. There is almost no mention of any dissenting voice in the hundreds of articles cited in the Waikato research reports and publications. Yet there have been such voices. These will be mentioned before developing my own criticisms of the position.

A problem confronting critics of Educational Constructivism is that it is a multi-faceted doctrine. Some constructivists are more occupied with learning theory, others with epistemology, and others with pedagogy. This makes criticism difficult because when one area is pressed, adherents deny commitments, saying they are really interested in another area. At one end there is, for want of a better term, *pedagogical* (or perhaps soft) constructivism. These constructivists are simply interested in children and strive to have engaging and meaningful lessons. Additionally they may believe in a number of educational commonplaces such as asking what students think about topics, and getting students to understand material. Pedagogical constructivists are not much interested in epistemological matters, nor are they worried too much about learning theory: as one leading Australian constructivist once said to me when pressed in a debate, 'Constructivism is just about good teaching'. However these classroom commonplaces are shared by most educational theorists, and they are hardly the stuff on which curricula and research projects are based. Pedagogical constructivism provides little, if any, guidance on educational purposes or curriculum content – whether for instance to adopt PSSC Physics or Harvard Project Physics, or whether to include Science-Technology-Society (STS) topics in a science programme. On all the important and pressing educational questions – what to teach, to whom, and when – constructivism is silent. Pedagogical constructivism goes to work in the service of the latest political foot that has trodden upon the curriculum. At the other end of the spectrum there is *theoretical* (or hard) constructivism. Constructivists at this end, although differing among themselves, do take seriously the various epistemological and psychological claims of constructivism. New Zealand constructivists range across the spectrum from pedagogical to theoretical.

Early Criticism

Kenneth Strike in 1987 focused on the relativism of constructivism, and the implications of this for teaching, saying that:

> If every idea is as good as every other and if that which certifies an idea for a particular student is the fact that it is a personal construct, it is simply mysterious as to why we should teach or why students should care what we teach.
>
> (Strike, 1987, p. 489)

He also drew attention to the public nature of concepts and the criteria for their correct use. Teachers mediate between the child's mind and this public, objective realm, by correcting children's conceptions.

In the same year, Jeremy Kilpatrick criticised the insularity and fervour of constructivists, observing that constructivism was akin to waves of religious fundamentalism that periodically sweep America. He said of constructivism that it has:

> A siege mentality that seeks to spread the word to an uncomprehending, fallen world; a band of true believers whose credo demands absolute faith and unquestioning commitment, whose tolerance for debate is minimal, and who view compromise as sin; an apocalyptic vision that governs all of life, answers all questions, and puts an end to doubt.
>
> (Kilpatrick, 1987, p. 4)

It is a moot point just how applicable this judgement is to New Zealand constructivism.

Joce Jesson, from the Auckland College of Education, wrote in 1991 during discussion of the *Draft Years 1-5 Science Syllabus,* that:

> ... constructivism ... has become part of the commonsense of science education: it is the new orthodoxy. As such there needs to be a deeper debate.
>
> (Jesson, 1991, p. 35)

In New Zealand this deeper debate barely occurred. She made an important point in observing that:

> Whereas Dewey's pragmatic philosophy is essentially social, personal construct theory or constructivism is essentially individual. ... Meaning is personal. This essentially dissolves science into an individual search for meaning.
>
> (Jesson, 1991, p. 37)

Jesson went on to say of the Waikato-inspired programme that:

> It merely changes science education from a predominantly theoretical subject to a more practical one. Its actual function may be as a way for middle-class teachers to teach working class children (whether these be Maori or Pakeha) how to be the new working class, by stressing the practical at the expense of the theoretical.
>
> (Jesson, 1991, p.43)

This is a serious criticism, and one that has been made across the world whenever schools restrict minority groups or the working class to fail-safe, ‘relevant’, practical courses. These courses lock them out of advanced study, and lock them out of professional, technical and well-paid employment, indeed increasingly out of any employment. Far from empowering people, they disempower.

In the following year, Wallis Suchting concluded a long and detailed philosophical analysis of Ernst von Glasersfeld’s radical constructivism – ‘Constructivism Deconstructed’ – with the opinion that:

> First, much of the doctrine known as ‘constructivism’ ... is simply unintelligible. Second, to the extent that it is intelligible ... it is simply confused. Third, there is a complete absence of any argument for whatever positions can be made out. ... In general, far from being what it is claimed to be, namely, the New Age in philosophy of science, an even slightly perceptive ear can detect the familiar voice of a really quite primitive, traditional subjectivistic empiricism with some overtones of diverse provenance like Piaget and Kuhn.
>
> (Suchting, 1992, p. 247)

The foregoing critiques of constructivism are hardly mentioned in New Zealand science education literature. The impression is given that ‘everyone is a constructivist’. This is just not so. There is a lively enough, if small, opposition to the doctrine and its educational programme.

Constructivism and Teaching the Content of Science

Some critics have been concerned that, despite all the promise, constructivism has yielded very little in the way of curriculum and pedagogical advice for teachers. This concern motivated a recent seminar at King’s College, London, whose participants:

> ... were seeking to explore, from deliberately critical standpoints, a movement that seems to have taken on a life of its own as *the* approach to understanding children learning science.
>
> (Black and Lucas, 1993, p. xii)

The seminar ‘arose from a belief that this field of work [children’s learning in science] has been strong in data and weak in theory’ (Black and Lucas, 1993, p. 230). It was also motivated by the realisation that the ‘extent to which the recent work on children’s intuitive ideas about the natural world has paid off in terms of improved classroom practice is so far disappointing’ (p. 190). Given that there have been in the past fifteen years something in the order of 2,500 studies undertaken on children’s learning of science, including studies of children’s science, of misconceptions in science learning, and of children’s alternative frameworks, the stance adopted in the seminar – that these studies lack a developed theoretical perspective, and that they have been educationally unhelpful – must be a challenge to constructivists in the science education community. The seminar participants recognised that ‘constructivism is the theoretical basis of much recent work’ (p. 232), but lamented that constructivism ‘provides only the general conditions for a theory’ (p. 232).

The lack of pedagogical guidance is especially apparent in relation to teaching the content of science. One prominent constructivist, Richard White, has said ‘although the research on alternative conceptions has sparked interest in content, it has not yielded clear advice about how to teach different topics' (Fensham, Gunstone and White, 1994, p. 255). Given the necessity for any science programme to teach the content of science, and given the hundreds of thousands of research dollars that have been spent on constructivist research, this is a serious failure. If constructivists do no more than advise teachers to 'ascertain what a child already knows and teach them accordingly', then they are akin to moralists who advise 'do good and avoid evil', or stock-brokers who advise 'buy cheap and sell dear'. The advice sounds alright, but it does not take you very far.

The two models of learning that constructivists most frequently turn to in order to flesh out their pedagogical recommendations are the Generative Learning Theory developed by Roger Osborne and Melvin Wittrock (Osborne and Wittrock, 1983, 1985), and the Conceptual Change Model of learning developed by George Posner, Kenneth Strike, Peter Hewson and others (Posner, *et al*., 1982). The first model has problems with teaching the content of science, with getting pupils to generate something that they know nothing about and which is foreign to them. The second model is not really a learning theory.

In their 1982 article, 'Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change' Posner *et al*., propose that, for individual conceptual change or learning to take place, four conditions must be met:

1) There must be dissatisfaction with current conceptions.
2) The proposed replacement conception must be intelligible.
3) The new conception must be initially plausible.
4) The new conception must offer solutions to old problems and to novel ones; it must suggest the possibility of a fruitful research programme.

Strike and Posner, in retrospect, describe their original conceptual change theory as 'largely an epistemological theory, not a psychological theory ... it is rooted in a conception of the kinds of things that count as *good* reasons' (Strike and Posner, 1992, p. 150). Their original theory is concerned with the 'formation of rational belief' (p. 152); it does not 'describe the typical workings of student minds or any laws of learning' (p. 155). So it is not a learning theory, rather it is a theory of rationality, it is a philosophical theory.

The difficulty for constructivism posed by teaching the content of science is not just a practical one, it is a difficulty that exposes a fundamental *theoretical* problem for constructivism – if knowledge cannot be imparted, and if knowledge must be a matter of personal construction, then how can children come to knowledge of complex conceptual schemes that have taken hundreds of years to build up? Many science educators are interested in finding out how, on constructivist principles, one teaches a body of scientific knowledge that is in large part abstract (depending on notions such as velocity, acceleration, force, gene), that is removed from experience (propositions about atomic structure, cellular processes, astronomic events), that has no connection with prior conceptions (ideas of viruses, antibodies, molten core, evolution, electromagnetic radiation), and that is alien to common-sense, and in conflict with everyday expectations and concepts? Joan Solomon, a prominent British science educator, well articulates the problem:

> Constructivism has always skirted round the actual learning of an established body of knowledge ... students will find that words are used in new and standardised ways: problems which were never even seen as being problems, are solved in a sense which needs to be learned and rehearsed. For a time all pupils may feel that they are on foreign land and no amount of recollection of their own remembered territory with shut eyes will help them to acclimatise.
>
> (Solomon, 1994, p. 16)

Constructivists addressed the problem at an international seminar held at Monash University in 1992. Its published proceedings were titled *The Content of Science: A Constructivist Approach to its Teaching and Learning* (Fensham, Gunstone and White, 1994).

Rosalind Driver, one of the most prominent of constructivist researchers, made a contribution to the Monash seminar on 'Planning and Teaching a Chemistry Topic from a Constructivist Perspective'. She and her co-workers had children put nails in different places and observe the rate at which they rusted. She remarked that:

> The theory that rusting is a chemical reaction between iron, oxygen and water, resulting in the formation of a new substance, is not one that students are likely to generate for themselves. (Driver, 1994, p. 206)

Indeed.

After ten pages describing how the teacher tries to 'keep faith with students' reasoning ... yet lead them to the intended learning goals' (p. 207), we are told that 'The process of investigating personal ideas and theories may lead students to reflect upon and question them. At the same time, it is unlikely to lead to the scientific view' (p. 218).

Quite so.

But where does this leave constructivism as a putatively useful theory for science teachers?

Most science teachers realise this difficulty. They try their best to explain things clearly, to make use of metaphors, to use demonstrations and practical work to flesh out abstractions, to utilise projects and discussions for involving students in the subject matter, and so on. They realise that many, if not most, things in science are beyond the experience of students and the capabilities of school laboratories to demonstrate. The cellular, molecular and atomic realms are out of reach of school laboratories, as is most of the astronomical realm. Most of the time even things that are within reach do not work. It is a rare school experiment that is successful. For children, a great deal of science has to be taken on faith. Good teachers do their best in the situation, and try to point out why faith in science is warranted.

Contrary to the rhetoric, constructivism, if taken seriously, is only a hindrance to good teaching. Teachers need to take children over the divide between their haphazard, largely narcissistic, beliefs arising from experience and everyday life to the realm of scientific (or mathematical, or historical, or literary) knowledge. The core constructivist idea that, as Beverley Bell once put it, 'knowledge is the personal construction of an individual and does not exist externally to be transmitted' (Bell, 1986, p. 6), is philosophically dubious and educationally unhelpful. It does nothing to bridge the conceptual gulf between science and children's ideas that everyone, constructivists included, recognise.

The conceptual content of science is a complex set of interrelated meanings that only occasionally make contact with experience or commonsense. Students may more or less adequately grasp these meanings (the difference between mass and weight, momentum and energy, experimental and control groups etc.), from what the teacher has provided, but the test of adequacy is whether the students end up with the correct, that is scientific, meaning for concepts they are using. Traditionally, for any subject, the teacher's task is to know the meanings, and to convey them in a clear and understandable manner.

For soft, or pedagogical constructivists, who allow the transmission of knowledge, there is no theoretical problem about the teaching of science content; the problems are just pedagogical or pragmatic ones. Another contribution to the Monash seminar by Victorian school teachers (Anne Symons, Kate Brass and Susan Odgers) on teaching using constructivist ideas, illustrates some of these points. They say that traditional teaching of biology, specifically the body, produces compartmentalised knowledge, 'which does not give an overview of the functioning of the whole organism' (p. 177). Traditionalists might say that the above problem can be solved by teaching a more comprehensive and integrated view of bodily systems; and does not necessitate the abandonment of traditional pedagogy, much less traditional epistemology. However the Victorian teachers wanted to introduce 'a more effective teaching and learning process' (p. 177), which meant giving the students a paper outline of the body and asking them to make and place cut-outs of internal organs on the drawing, and illustrate the connections between the organs. They were to have 'responsibility for their own learning' (p. 177). Although they were to have responsibility, nevertheless the teachers decided the subject for study, and determined that group work would be the *modus operandi*, with students being given a one lesson crash-course in group functioning (it is nice to see progressive teachers being authoritarian about the really important things). Then, 'to get the students started they were told that the heart is approximately the same size as a fist' (p. 180).

To the naive observer, there seems to be a lot of traditional teacher-directed pedagogy, and transmission of knowledge going on here. Which is sensible, even if it violates hard constructivist tenets. If you tell a class that the heart is the same size as a fist, why not tell them that there is a left and right ventricle and so on? The limits appear not to be epistemological or theoretical, but just plain old pedagogical – what is going to work best for these kids, at this time, in this place, with these examination commitments? The Victorian's lesson may have worked well. However there is no theoretical or pedagogical conclusion to be drawn from it.

The absurdities foisted on teachers (and students) by hard constructivism are evident in another contribution to the Monash seminar where the authors say that their 'science lessons are student centred' and that teachers need not know their subject. Admission of teacher ignorance 'has benefits for the students: it gives them confidence' (Fensham, Gunstone and White ,1994, p. 99). This seems counter-intuitive, and contrary to the notion of a professional and competent teaching service. The British educator R.F. Dearden, in a critique of a comparable proposal put forward in England, said:

> How it is that a person himself ignorant of science is nevertheless able to 'provide [learning] opportunities' and reliably to ascertain that scientific 'discoveries' are in fact being made by his class is left unexplained in this article. But there cannot be many practising teachers who suppose that ignorance of anything is a qualification for teaching it. To teach something in ignorance of it is not just difficult: it is logically impossible.

(Dearden, 1967, p. 143)

Pleasingly the 'ignorance is bliss' view was not shared by all contributors to the Monash seminar. Laurence Viennot and Sylvie Rozier, in their essay on teaching mechanics and thermodynamics, advise teachers that, when working with students' 'soft' [naive] explanations, they should not 'hide the dangers of a careless extension of such explanations to other cases'. They should, for instance, tell students that pressure-altitude relationships only hold if the 'molecules have (more or less) the same velocity in the two compared cases' (p. 252). This seems like a good old-fashioned case of the transmission of knowledge from someone who has it (the teacher), to someone who is wanting to get it (the student). Viennot and Rozier recognise that in teaching Newton's third law 'it is difficult to reach the more subtle level of vigilance without a very clear view about the physics at stake' (p. 253).

If content cannot be taught, and if teachers do not need to know the subject matter, then teacher process skills are substituted for content knowledge in constructivist classrooms. Along with this substitution goes 'content-free' exams. An effect of this is that naturally bright kids will always do well at school – they do not need to know content and they are able to quickly read and understand the questions – whilst average kids, who previously could have worked hard and learned the content, will always remain average in school results.

Viennot and Rozier say that 'ultimately the most crucial "pedagogical outcome" of studies of students' ideas is that teachers should discuss their teaching goals' (p. 238) . Given that there have been about 2,500 such studies in the past two decades (Duit, 1993), this surely is a case of the mountain that shook and produced a mouse. This observation is a pedagogical commonplace. Since at least Plato's time, good teachers have realised that they need to think carefully about their aims and that these aims affect the methods they use in teaching.

Constructivism and the Aims of Education

Guy Claxton, a participant in the King's seminar, raised a fundamental matter when he commented that 'In order to draw conclusions about how to teach on the basis of the 'Alternative Frameworks' research, we have first to clarify our aims' (Black and Lucas, 1993, p. 190).

Precisely. And constructivism gives no guidance on this crucial point. Constructivist learning principles, such as they are, can be equally utilised for the teaching of Stalinism, Astrology, Racism or any other unpalatable system; the principles are neutral with respect to the truth or falsehood of the content, the desirability or otherwise of the goal. Studies of small group behaviour in social psychology show that just about anyone can be brought to believe anything through negotiation and influence. *How* they come to believe (the subject matter of learning theory) is interesting; *what* they should believe (the subject matter of epistemology and educational theory) is more important. Constructivists are, *qua* constructivists, silent on this. However, in the absence of any serious philosophy or educational theory, they make shallow and faddish pronouncements on the topics.

Claxton asks 'What kind of learning do we wish to produce? Are we aiming for deep understanding, fluency of symbolic manipulation, accurate recall, or every day competence, for example?' (p. 190). He recognises that these psychological questions rapidly lead into philosophical questions about the 'purposes for which school science might be taught' (p. 191). It is not clear that constructivism, as a theory of learning, contributes much to the answering of these questions.

Liberal education is concerned with the mastery of a range of intellectual and practical skills, and for the utilisation of these competencies in the promotion of personal and social goods – on this see Hirst 1974, Dressel 1979, Bantock 1981 ch.4, and Mark 1994. With mastery comes intellectual independence and autonomy. For instance, Israel Scheffler, the recently retired Harvard professor of education and philosophy, and champion of liberal educational ideals, is a strong critic of Kuhnian-inspired subjectivism, constructivism and relativism in philosophy of science (Scheffler 1982), yet he is an advocate of autonomy as an educational aim, saying at one point in discussion of possible school curriculum content that:

> Content should enable the learner to make responsible personal and moral decisions. Self-awareness, imaginative wieghing of alternative courses of action, understanding of other people's choices and ways of life, decisiveness without rigidity, emancipation from stereotyped ways of thinking and perceiving – all these are bound up with the goal of personal and moral self-sufficiency.
>
> (Scheffler, 1973, p. 124)

The sciences have a contribution to make to this liberal educational goal if they are taught in a contextual manner which does justice to richness of the scientific tradition. Scheffler recognises this when he goes on to say:

> the natural sciences and mathematics may be seen not merely as technical equipment but as rich fields for the exercise of imagination, intuition, criticism, and independent judgment. ... but such decision-making also requires reliable knowledge,embodied in several areas of study.
>
> (Scheffler, 1973, p. 124)

And he recognises something often ignored by constructivist, child-centered, and progressive educators:

> Finally, beyond the power to make and carry out decisions, self-sufficiency requires intellectual power. Content, that is, should provide theoretical sophistication to whatever degree possible ... ignorance is a danger.
>
> (Scheffler, 1973, p. 125)

CHAPTER 5

EPISTEMOLOGY AND CONSTRUCTIVISM

A theory of knowledge, or epistemology, is at the heart of any theory of instruction, teaching or education. All teachers have an implicit epistemology, even if it is not given explicit expression. Constructivists take seriously teachers' epistemology, and seek to reshape it to their own account. This chapter will continue the critique of constructivism by examining its theory of knowledge.

The Role of Epistemology in Constructivism

Our ideas about knowledge – what constitutes it, how people attain it, and how it is measured – will clearly influence our ideas about teaching, learning and assessment. This has been true since Socrates assisted the slave boy in the *Meno* to come to an understanding of Pythagorus's theorem. It was Socrates' account of knowledge that led to the questioning form of instruction used, the Socratic Method, as it became known. Lee Shulman, the influential U.S. educationalist, recognises this when he says, as previously mentioned:

> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice.
>
> (Shulman, 1986, p. 9)

To explain why a particular proposition – for instance a proposition about genetic inheritance, or the conservation of energy, or the valency of sodium – is deemed warranted, worth knowing, and how it relates to other propositions, assumes both a knowledge of science and an epistemology of science. In classrooms this knowledge is crucial when children's experimental results and observations are often at variance with what they are asked to believe, where there is an evidential gulf between experience and knowledge.

Ernst von Glasersfeld, perhaps the leading figure in educational constructivism, correctly states that epistemology, or theory of knowledge, is the central and unifying plank in constructivism. In one of his publications he says:

> The word 'knowledge' refers to a commodity that is radically different from the objective representation of an observer-independent world which the mainstream of the Western philosophical tradition has been looking for. Instead 'knowledge' refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider *viable*.
>
> (Glasersfeld, 1989, p. 124)

At another point he says:

> Our knowledge is useful, relevant, viable, or however we want to call the positive end of the scale of evaluation, if it stands up to experience and enables us to make predictions and to bring about or avoid, as the case may be, certain phenomena (i.e., appearances, events, experiences) ... Logically, that gives us no

> clue as to how the 'objective' world might be; it merely means that we know one viable way to a goal that we have chosen under specific circumstances in our experiential world. It tells us nothing ... about how many other ways there might be.
>
> (Glasersfeld, 1987, p. 199)

Epistemology drives constructivist curricular and pedagogical proposals. Jere Confrey, a U.S. mathematics educator, has said that:

> Put into simple terms, constructivism can be described as essentially a theory about the limits of human knowledge, a belief that all knowledge is necessarily a product of our own cognitive acts. We can have no direct or unmediated knowledge of any external or objective reality. We construct our understanding through our experiences, and the character of our experience is influenced profoundly by our cognitive lens.
>
> (Confrey, 1990, p. 108)

And Grayson Wheatley, a Canadian science educator, has said:

> The theory of constructivism rests on two main principles ... Principle one states that knowledge is not passively received, but is actively built up by the cognising subject ... Principle two states that the function of cognition is adaptive and serves the organisation of the experiential world, not the discovery of ontological reality ... Thus we do not find truth but construct viable explanations of our experiences.
>
> (Wheatley, 1991, p. 10)

Rosalind Driver believes that:

> Although we may assume the existence of an external world we do not have direct access to it; science as public knowledge is not so much a discovery as a carefully checked construction.
>
> (Driver and Oldham, 1986, p. 109)

Steven Lerman (1989), following Kilpatrick (1987) and earlier, von Glasersfeld, suggests that the core epistemological theses of constructivism are:

1. Knowledge is actively constructed by the cognising subject, not passively received from the environment.
2. Coming to know is an adaptive process that organises one's experiential world; it does not discover an independent, pre-existing world outside the mind of the knower.

Epistemology in the Classroom

Epistemology is important for all educators because of its background role in informing curriculum proposals, and guiding classroom procedures, but it is especially important for constructivists because epistemology is actually taught in their classroom; it constitutes an explicit part of the content of science and mathematics instruction. Thus there is an additional reason for close scrutiny of constructivist theory of knowledge.

Rosalind Driver and her co-workers at Leeds University, say that ‘Science learning, viewed from a constructivist perspective, involves epistemological as well as conceptual development’ (Driver *et al.* 1994, p. 219). They cite the Waikato contribution to the Monash seminar as exemplifying this position. It is then crucial to examine what is meant by epistemological development. Without examination, and even with it, there is a strong temptation for all teachers to define epistemological development as ‘believing what I believe about epistemology’.

Two North American constructivists, Wolff-Michael Roth and Anita Roychoudhury, fall prey to this temptation, saying that:

> If the epistemological development is partly a factor of age, then we could simply wait for the students to become constructivists, the most mature epistemological commitment ... For us practitioners, this is not a satisfactory solution. However, simply exposing students to an environment in which a constructivist epistemology is implicit may not be sufficient ... Time should be provided to discuss ... the plurality of languages for describing reality.
>
> (Roth and Roychoudhury, 1994, p. 28)

And they are pleased that when subject to the above regime:

> There seem to be considerable shifts in the students’ views of scientific knowledge toward a more constructivist-relativist stance.
>
> (Roth and Roychoudhury, 1994, p. 28)

Many other examples can be cited of the constructivist commitment to incorporate teaching about the nature of science into science teaching. There can be no in-principle objection to this, as I argue at length in my recent book (Matthews, 1994). The problem arises when this perfectly sensible proposal is interpreted to be teaching the *constructivist* nature of science. Roth and Roychoudhury believe that constructivism is the ‘most mature’ epistemological position, and they consciously set out to convert their students to the constructivist cause. But if constructivism is fundamentally flawed, then the work of Roth, Roychoudhury and others similarly inspired with bringing pupils into the constructivist fold, is educationally and socially disastrous.

Thomas Kuhn and Constructivist Pedagogy

The contribution of the Waikato group to the Monash seminar stresses that reconceptualisation of teachers’ views of the nature of science and of learning in science is important for a constructivist pedagogy (Carr, *et al.*, 1994, p. 147). They, like many constructivists, look to Thomas Kuhn for insight into the nature of science. David Hawkins, in his Introduction to the Monash seminar, also mentions Kuhn’s ‘carefully analysed historical shifts in the presuppositions of scientific investigation and thought’ (Hawkins, 1994, p. 10) to ‘support constructivism and the older philosophies of relativism and subjectivism that are its precursors’.

There is a major problem with this widespread constructivist embrace of Thomas Kuhn: Kuhn argued for an authoritarian science pedagogy. In 1959 he maintained that science education should be the initiation into an unequivocal tradition and that students must begin by learning a good deal of what is already known. His view that conservative education was the prerequisite for successful innovation in science provided the title both for his 1959 address to the conference on Creativity, and also the title of his 1977 anthology, *The Essential Tension*. He observed that science education was the 'initiation into an unequivocal tradition' (Kuhn, 1977, p. 237), and that 'no part of science has progressed very far or very rapidly before this convergent education ... became possible' (Kuhn, 1977, p. 237). In another publication, 'The Function of Dogma in Scientific Research', Kuhn noted that science education 'inculcates what the scientific community had previously with difficulty gained – a deep commitment to a particular way of viewing the world and of practising science in it' (Kuhn, 1963, p. 349), and that it remains 'a relatively dogmatic initiation into a pre-established problem-solving tradition that the student is neither invited nor equipped to evaluate' (Kuhn, 1963, p. 351). These conservative educational views were repeated in his *Structure of Scientific Revolutions*.

Just as there are arguments, previously mentioned, about Kuhn's epistemology and his account of scientific change, so too are there arguments about Kuhn's vision of desirable science education. Clearly constructivists cannot just invoke his name in order to support their pedagogy. Kuhn's view of science education is most unconstructive.

If teachers consciously want to transform the epistemological beliefs of their students, then they need to reflect seriously on epistemology. If this is not done, then the opportunity for personal and cultural damage is significant. The dangers of scientism are well known, it is conducive to narrow-minded arrogance and simplistic reductionism of all kinds. On the other hand a steady diet of relativism and constructivism in schools – not just in humanities and the arts, but in science as well – has the potential to corrupt public debate and undermine scientific and social institutions. If, on matters of grave public concern, there is no truth to be ascertained, then rhetoric can be substituted for argument, propaganda for investigation and alternative, non truth-seeking goals proposed for research. Some of the dangers inherent in abandoning truth as the goal of science can be seen in pronouncements of the Nazis. Hans Schemm, the Nazi Minister for Culture and Education in Bavaria, in an address to Munich professors said:

> From now on, the question for you is not to determine whether something is true, but to determine whether it is in the spirit of the National Socialist revolution.
>
> (Beyerchen, 1977, p. 52)

If referring to Nazis seems too far-fetched, then Marxist, Maoist, monetarist, feminist, multiculturalist, Thatcherist, postmodernist, Islamic, ecological, or any other politically correct doctrine can be substituted for National Socialist in the above. Once truth is abandoned in a culture, how does a culture counter arguments advanced by the likes of Schemm above? Since Socrates, the best educational traditions have been concerned with both the reproduction and the critique of their culture. The systematic relativism of constructivism undermines the latter function.

Problems with Constructivist Epistemology

The three major problems in constructivist theory of knowledge are its empiricism, its instrumentalism, and its individualism.

Constructivism as a Form of Empiricism

Wallis Suchting, in a detailed critique of constructivism concluded that:

> In general, far from it being what it is claimed to be, namely, the New Age in philosophy of science, an even slightly perceptive ear can detect the familiar voice of a really quite primitive, traditional subjectivistic empiricism with some overtones of diverse provenance like Piaget and Kuhn.
>
> (Suchting, 1992, p. 247)

Any epistemology which formulates the problem of knowledge in terms of a subject looking at an object and asking how well what they see reflects the nature or essence of the object, is Aristotelian, or more generally empiricist. Aristotelians were direct realists about perception, that is the objects of perception were material bodies, humans had direct access to the real world; later empiricists were indirect realists, that is the objects of perception were personal sense impressions generated, it was supposed, by material objects that were never directly apprehended. Locke, an avowed opponent of Aristotle, in his 1689 *Essay* puts the matter this way: 'The mind, in all its thoughts and reasonings hath no other immediate object but its own ideas, which it alone does or can contemplate'.

Beginning with the British Empiricists, experience, not the world, becomes the subject of our knowledge claims. David Hume provides a characteristically clear statement of their position:

> It is a question of fact, whether the perceptions of the senses be produced by external objects, resembling them: how shall this question be determined? By experience surely: as all other questions of a like nature. But here experience is, and must be entirely silent. The mind has never anything present to it but the perceptions, and cannot possibly reach any experience of their connection with objects. The supposition of such a connection is, therefore, without any foundation in reasoning.
>
> (Hume, 1717/1902, p. xx)

Locke's formulation of the problem of knowledge was used by Berkeley to support idealism and relativism. Berkeley's argument in his *Treatise* was simple but devastating: 'As for our senses, by them we have the knowledge *only of our sensations*, ideas, or those things that are immediately perceived by sense, call them what you will: but they do not inform us that things exist without the mind, or unperceived'.

Modern constructivists have embraced this subjectivism and its epistemological retreat from the real to the self. For constructivists, personal experience, or sensation, is substituted for external reality as the object of knowledge claims. Antonio Bettencourt is just one of many constructivists who say:

> ... constructivism, like idealism, maintains that we are cognitively isolated from the nature of reality. ... Our knowledge is, at best, a mapping of transformations allowed by that reality.
>
> (Bettencourt, 1992, p.46)

It is not coincidental that modern constructivists once having formulated the epistemological problem in Aristotelian-Lockean terms then endorse versions of Berkeley's savage critique of it and end up with relativism and, for the more consistent, idealism.[1] For instance, Antonio Bettencourt affirms that 'constructivism is the view that reality is itself constructed' (Bettencourt, 1992, p. 46). This is an interesting, but contentious, claim. It results from confusing the non-constructed object of knowledge, reality, with the constructed means (our theoretical constructs) whereby we gain knowledge of that reality. Once this confusion is pointed out, then this particular constructivist argument for idealism collaspes. A story of Brecht is apposite here:

> Teacher: Si Fu, name the basic questions of philosophy.
>
> Si Fu: Are things external to us, self-sufficient, independent of us, or are things in us, dependent on us, non-existent without us?
>
> Teacher: Which opinion is the correct one?
>
> Si Fu: There has been no decision about it.
>
> Teacher: Why does the question remain unresolved?
>
> Si Fu: The Congress which was to have made the decision took place two hundred years ago at Mi Sang monastery, which lies on the bank of the Yellow River. The question was: Is the Yellow River real or does it exist only in people's heads? But during the congress the snow thawed in the mountains and swept away the Mi Sang monastery with all the participants in the Congress. So the proof that things exist externally to us, self-sufficiently, independently of us was not furnished.
>
> (*Turandot* scene 4A, in Suchting, 1986, p. 53)

This idealism is sometimes apparent in New Zealand constructivism. Thus, for instance, the third Waikato LISP project was concerned with learning the energy *concept*, not learning about energy. Malcolm Carr and Valda Kirkwood write, in the article that summarises the third LISP Energy Project, of 'energy being an idea made up by people to organise and clarify their world. Energy is a human construct' (Carr and Kirkwood, 1990, p. 43). This is standard instrumentalism regarding theoretical terms in science; and is suggestive of the above sceptical view that scientific research on energy relationships is not telling us anything about the world, only about our ideas. It is a truism that 'energy' is a human construct: all of our constructs are human constructs. The crucial issue is whether or not our constructs correspond to anything in the world: Is there energy in the world, or just in our minds? Victims of earthquakes, volcanic eruptions or the Yellow River flood, might reasonably think the former.

Within this empiricist framework the possibility of knowledge weakens once it is pointed out that the mind is active in cognition and in structuring the experiences that the senses provide. The possibility of knowledge evaporates if the immediate objects of the mind are sense impressions rather than nature itself. Nature, or in Kant's terms, the thing-in-itself, becomes unknowable, because we are only ever aware of our sense impressions and are thus unable to check the correspondence of our thought to reality.

Constructivism's acceptance of the fundamentals of the Aristotelian, empiricist epistemological framework is indicated when von Glasersfeld speaks of 'looking through distorting lens and [agreeing] on what they see', and Confrey speaks of 'cognitive lens', and when numerous others have recourse to this looking/seeing/observing vocabulary for stating the problem of knowledge, or when use is made of the Kuhnian/Hansonian hidden figures to establish facts about the theory dependence of observation, or when gestalt-switch terminology is used to describe scientific revolutions.

The one-step argument from the psychological premise 'the mind is active in knowledge acquisition' to the epistemological conclusion 'we cannot know reality' is endemic in constructivist writing. Leeman speaks for many when he says of the two theses – (1) and (2) at the beginning of this chapter – that 'the connections between hypothesis (1) and (2) seem to be quite strong' (Lerman, 1989, p. 212).

But this conclusion only follows on the Aristotelian assumption that any subjective interference with the data of experience distorts human knowledge of the world. If this assumption is rejected, then none of the sceptical constructivist conclusions follow. And certainly the Bettencourt idealist argument that (1) – the activity of the mind in knowledge acquisition, leads to (3) – reality is constructed, does not follow.

Instrumentalism and constructivism

Constructivist doctrine leads to an instrumentalist interpretation of scientific theory, which is at odds with the orthodox realist view that science aims to understand the external world and is partially successful in that aim. George Bodner, an American constructivist, provides a frank endorsement of instrumentalism:

> The constructivist model is an instrumentalist view of knowledge. Knowledge is good if and when it works, if and when it allows us to achieve our goals.
>
> (Bodner, 1986, p. 874)

To his credit, at least for consistency, he went on to align himself with the sixteenth century theologian Osiander, the instrumentalist champion in one of the great showdowns between instrumentalism and realism in the history of science. Bodner admits that:

> A similar view was taken by Osiander, who suggested in the preface of Copernicus' *De Revolutionibus* [that] 'There is no need for these hypotheses to be true, or even to be at all like the truth; rather, one thing is sufficient for them – that they yield calculations which agree with the observations'.
>
> (Bodner, 1986, p. 874)

One century after Osiander had inserted his preface in Copernicus' epochal book, Cardinal Bellamine in 1615 was to offer this same instrumentalist olive branch to Galileo to save him from the Inquisition. Bellamine said:

> For there is no danger in saying that, by assuming the earth moves and the sun stands still, one saves all the appearances better than by postulating eccentrics and epicycles; and that it is sufficient for the mathematician. However it is different to want to affirm that in reality the sun is in the centre of the world ... this is a very dangerous thing.
>
> (Finocchiaro, 1989, p. 67)

As is well known, Galileo rejected the olive branch. He thought that Copernicanism described the world, not just something about our experiences or sensations. Galileo thought that Copernicus provided more than just a convenient tool for rearranging the calendar. Galileo was a realist about the aims of science, saying:

> Nature did not make human brains first, and then construct things according to their capacity of understanding, but she first made things in her own fashion and then so constructed the human understanding that it, though at the price of great exertion, might ferret out a few of her secrets.
>
> (In Burtt, 1932, p. 68)

In his *Two Chief World Systems* (1633) he repeats Copernicus' claim against Ptolemy that:

> However well the astronomer might be satisfied merely as a calculator, there was no satisfaction and peace for the astronomer as a scientist ... although the celestial appearances might be saved by means of assumptions essentially false in nature, it would be very much better if he could derive them from true suppositions.
>
> (Galileo, 1633/1953, p. 341)

In philosophy there has been a history of debate about realist and instrumentalist interpretations of scientific theory (see Matthews, 1994, chap. 8, for a guide to the literature). Constructivists give a very one-sided interpretation of this debate when they present instrumentalism as the 'mature epistemological position' (Roth and Roychoudhury, 1994, p. 7). For instance, Albert Einstein after an initial flirtation with instrumentalism became a realist (Holton, 1970). Most scientists, with some exceptions, have been realists.

One exception is the New Zealand Minister of Education, The Honorable Lockwood Smith PhD. In a personal letter during the 1993 science education debate said:

> I was rather surprised by some of your assertions in your *Herald* article. My own field of study was in nutrition, digestive physiology and protein metabolism.
>
> There is no way I, or my fellow scientists at the time, believed we were striving 'to find out the truth about the world'.
>
> Rather, what we were trying to do was develop hypotheses for how things might work and then test those hypotheses through objective observation and measurement. As research techniques have improved, inevitably explanations for observed phenomena have changed. It would have been foolhardy indeed to pretend that the best possible explanation at the time represented the 'truth'.
>
> (Smith, 1993)

The Minister here confuses two things. First, the aim of science with its realisation; and second, established science with frontier science. Realists maintain that science is *trying* to find out how the world is constituted, they do not maintain that all science is successful. Lockwood Smith rejects the former because of instances of failed science. The argument simply does not follow. (Although, to be fair, the Minister seems confused about what he believes on this matter. He denies 'striving to find the truth', but he does develop ‘hypotheses for how things might work’. These do seem to be pretty much the same thing.) Second, there may well have been areas of protein metabolism in which his work, and that of his colleagues, was rightly speculative and hesitant. However that is no reason why we should not believe in molecules, or proteins, or atoms, or enzymes, or chromosomes, or cells, or the countless other micro-constitutents of living things that science has revealed to us. To say, quite reasonably, that we do not know everything, is not to say that we know nothing. When a country’s Minister for Education argues this way (or is advised by his officials to do do), then the country is in deep trouble.

The Minister and other constructivists ought to explain to science teachers why they are being urged to adopt a minority tradition in the history of science. And why they are being asked to endorse, for instance, the enemies of Galileo, when most would have thought the teacher’s role was to help children appreciate intellectual and moral courage like Galileo’s in expounding his beliefs despite the pressure of the Inquisition.

Further, teachers can appeal to the traditional, and realist, scientific goal of learning about the world to justify the hard work involved in learning science. When the country’s Minister of Education and the official constructivist lobby deny that science is telling us anything about the world, then this justification is taken from teachers.

The social dimension of thought and knowledge

The third weakness in constructivist epistemology is that it radically underestimates the degree to which individual knowledge is dependent upon social reality. Individual understanding and conceptualisation is dependent upon the community’s knowledge and language. As Paulo Freire said twenty years ago, it is the ‘we think’ that determines the ‘I think’, not the other way around. This was a restatement of Hegel’s recognition that an individual mind is an aspect of the public mind. This is the epistemological face of John Donne’s observation that ‘No man is an island complete unto himself’. Knowledge is a social or public category. Knowledge, as distinct from beliefs, or thought more generally, implies some public standard or yardstick of attainment. This is the thrust of Popper’s assertion that individual understanding (for Popper a second world event), is dependent upon objective, social, understanding or knowledge (third world entities). The British philosopher of education, Paul Hirst, endorsed this position:

> ... the development of reason is seen as a fundamental social construction. It is only through shared conceptual schemes that objective judgements are possible, and it is in the creation of public languages alone that knowledge and understanding can be achieved and secured as a progressively developing public deposit.
>
> (Hirst, 1991, p. 42)

Vasili Davydov, a Russian linguist and follower of Vygotsky, has stated the social, as against the private, view of the origin of language and concept formation:

> The child does not create his own speech, his own verbal meanings, and does not determine the range of their object attributions – he masters the speech of adults and receives a number of visible objects from them, which are designated by these words.

(Davydov, 1990, p. 179)

It is for these reasons that teachers have to be initiators, they have to introduce children to the language, logic and conceptual structures of science; they are the points of connection between the wider scientific tradition and neophytes who do not have the vocabulary, the concepts, the methods, or the logic of science. This in turn means that teachers should have an appreciation of that scientific tradition, of its methods and logic, its history, its achievements, and of its place in the intellectual scheme of things. This is especially important when, as at present, there are energetic pseudo-scientific modes of thinking competing for children's allegiance. Children are able to discover truths, but only if they have been suitably outfitted for the journey of discovery. The outfitting involves words, concepts, conceptual structures, and logic. These are the intellectual equivalents of clothing, food, compasses and maps which are necessary for geographical discovery. In both cases the discoverers depend upon something beyond themselves being given to them.

Children's thoughts are private, but their concepts are public. Whether or not particular thoughts are going to constitute knowledge is not a matter for the individual to determine. Teachers, and the education system more generally, mediate between student beliefs and public standards. Without such public criteria, the word 'knowledge' is reducible to 'belief'. Paul Hirst has clearly expressed this point:

> ... it is a necessary feature of knowledge as such that there be public criteria whereby the true is distinguishable from the false, the good from the bad, the right from the wrong. It is the existence of these criteria which give objectivity to knowledge.
>
> (Hirst, 1974, p. 43)

After an initial enthusiasm for the idea of private construction of knowledge, constructivists have begun to adjust to the obvious weaknesses of the position. Some have moved from the personal constructivism promoted by Ernst von Glasersfeld, to a more social constructivism as found in Duckworth (1987) and Lave (1988). Constructivists in New Zealand are moving from the implausible personal constructivism that many originally held – wherein feral children could presumably generate science – to social constructivism. Beverley Bell in 1993 said:

> Learning involves both the personal and social construction of meaning. Learning is more than just the individual construction of meaning and involves students constructing ideas that are part of the knowledge collectively constructed by the scientific community.
>
> (Bell, 1993, p. 45)

Pleasingly we are now told that students have to construct ideas that are part of the knowledge collectively constructed by the scientific community. One would think that if they *have to* construct the ideas of scientists, they could more easily be taught them. However this violates the precious Principle of Non-Communication of Knowledge. How, even on this modified social constructivist view, students are going to construct ideas of acceleration, potential energy, evolution, force, inertia, valency, mass, and so on – the conceptual structures of science – without being taught them is a mystery. And why they should have to construct them if they have no special truth status is even more of a mystery.

One experienced science teacher who has taught in both Singapore and New Zealand, remarked on the difference between them as being: ‘In Singapore, if a student says something silly in physics, they are told ‘that is wrong’. In New Zealand, they are told ‘that is an interesting idea’”. This accords with the previously quoted constructivist idea of the role of teachers as ‘gardeners, tour guides, learning councillors or facilitators rather than dispensers of information or judges of right and wrong answers’ (Roth and Roychoudhury, 1994, p. 27), and it indicates the extent to which constructivist ideas have infiltrated New Zealand education. There is an obvious contrast between this model of teaching and what the Hungarians quoted earlier in this book recalled of their teachers and education:

> Our gymnasium teachers had a vital presence. To kindle interest and spread knowledge among the young – this was what they truly loved.
>
> (Marx, 1994, p. 175)

Michael O’Loughlin is one science educator who has taken social constructivism to its limits by developing a ‘Sociocultural Model of Teaching and Learning’ (O’Loughlin, 1992). In doing so he displays the strengths, but also the weaknesses of the position. He says that ‘my central thesis is that [personal] constructivism is flawed because of its inability to come to grips with the essential issues of culture, power, and discourse in the classroom’ (O’Loughlin, 1992, p. 791). He asks ‘Does constructivist theorizing include consideration of how issues such as the cultural and political nature of schooling and the race, class and gender backgrounds of teachers and students ... influence the kinds of meanings that are made possible in the classroom?’ (O’Loughlin, 1992, p. 792). He criticises Piagetian developmental theory for its ahistorical and acultural universalism, for its concentration on the ideal ‘epistemic subject’ rather than actual learners. He observes that ‘real difficulties arise, however, when constructivists appropriate this universalist theory to deal with classroom learning processes that are inherently constrained by sociocultural and contextual factors’ (O’Loughlin, 1992, p. 795). He is against child-centered constructivist classrooms and pedagogy because children still ‘learn that the voice of authority, whether teacher or text, is privileged and authoritative’ (O’Loughlin, 1992, p. 807), and furthermore, that ‘this kind of environment may have a particularly deleterious effects on the learning potential of students from cultural groups other than the white middle class’ (O’Loughlin, 1992, p. 807).

O’Loughlin exemplifies the case I have been arguing: namely, that epistemology is central to constructivism, but the epistemology is usually confused and deficient. O’Loughlin politically outflanks simple constructivists, to say nothing of traditionalists, by the rousing assertion that knowing is ‘a process of examing current reality critically and constructing critical visions of present reality and of other possible realities so that one may become empowered to envisage and enact social transformation’ (O’Loughlin, 1992, p. 799). Poor old Galileo’s discovery of the laws of free fall and of parabolic motion seem quite tame by this ‘critical’ standard of knowing, as do Mendel’s painstaking investigations of a basis for heredity. They seem hardly to be knowledge. But Hitler’s *Mein Kampf* looks really good. Although O’Loughlin displays plenty of concern with politics, criticism, and empowerment, his position is strangely bereft of serious epistemology.

If knowledge is degraded to whatever makes sense to you, or whatever suits your interest, or whatever is viable in your experiential world, then why, given low salaries and atrocious working conditions, teachers would have a vital presence, or would see their life work as the kindling of interest in, and spread of knowledge, becomes a mystery. Why should John Scopes have, in 1923, defied the State of Tennessee and insisted on teaching Darwinism? Why should the courageous few Japanese teachers defy their government and insist on saying that Japan invaded China in the prelude to the war in the Pacific? Constructivism, despite perhaps its initial attraction, ultimately undermines the *raison d'être* of teaching.

CHAPTER 6

PROBLEMS FOR NEW ZEALAND SCIENCE EDUCATION

I have mentioned some critics of constructivism, and have focused on problems with the constructivist theory of knowledge. I have argued that constructivist epistemology is basically old Aristotelian empiricist wine in postmodernist bottles, and that the wine's use-by-date expired with the scientific revolution initiated by Galileo and completed by Newton in the seventeenth century.

This core epistemological weakness has flow-on effects in other crucial domains, ones having a particular pertinence for New Zealand. Five of these domains will be mentioned: teacher education, women and science, Maori science education, science and society relations, and curriculum structure.

Misguided Teacher Education

Everyone recognises that capable teachers are the key to successful education. Good teachers can salvage the worst curriculum and compensate for appalling school conditions, and poor teachers can wreck the best curriculum and squander the most expensive facilities. Debate about the curriculum in New Zealand is important, but more important is the quality of teachers because they interpret and deliver the curriculum, they motivate students to learn, and they are the representatives of the scientific tradition into which pupils are being introduced. Constructivists have views about the qualities of good teachers and their roles. With some exceptions, these views are unhelpful and misguide teacher education.

The 1993 Teacher Development Report

In 1993, after five years of research, the fourth LISP project was published . It was concerned with Teacher Development (that is, in-service courses for practising teachers) and was overseen by Dr Beverley Bell. It consumed a large amount of government research funds. Its opening pages signal its continuity with the earlier LISP studies, and reveals the 'closed-shop' nature of New Zealand science education:

> ... to implement the new curricula, teachers were and still are being asked to implement or take into account the findings of the Learning in Science Projects. In acknowledgement that the successful implementation of a new curriculum requires teacher development, major contracts have been let for teacher development.
>
> (Bell, 1993, p. 6)

The report's ideas about teacher development represent a continuation of those in the 1990 *Draft Forms 1-5 Science Syllabus*, which was also written by Dr Bell to address the findings of the still earlier LISP projects. The 1990 *Draft* itemises 'The Role of the Teacher' as being:

> Helping students learn how to learn.
>
> Being a learner too.
>
> Ensuring equity for all students.

Creating friendly, supportive learning environment.

Providing learning opportunities.

Listening to students.

Using the students' ideas, experiences, and interests.

Challenging sensitively the ideas of students.

Providing resources to help students learn.

Ensuring students communicate in a variety of modes.

Identifying and nurturing the scientific talent and interests of all students (provided that teachers are aware of the effectiveness of an open science programme which allows students to realise their potential at their own pace).

Contributing to the planning of the school science programme.

(Bell, 1990, p. 11).

There is no objection to any of this, except that we are being given the icing but not the cake. Or to change metaphors, all of the above constitutes warm-up exercises for teaching, it does not address the central business of teaching. The central responsibility of a teacher is to know his or her subject and to teach it in a clear, engaging and thoughtful manner. And as professionals, or as educators, teachers need to know why they are teaching the subject and why students should learn it. That is, they need some lively sense of the personal and social importance of their subject. Neither subject matter knowledge, nor knowledge of the history and philosophy of the subject, rate a mention in this 1990 twelve-item characterisation of the role of a teacher. Their absence is revealing.

The 1993 *Teacher Development* Report runs to over 400 pages, and concludes with a 20 point check-list for 'Evaluating Teacher Development Programmes'. Among the matters to be checked are:

3. To what extent and in what ways does the programme provide opportunities and help for personal development?
4. To what extent is the programme promoting the social development of the teachers?
6. Are the teachers able to choose the group of teachers they work with so they feel their development is occurring with a group of teachers like me?
10. What provision is made for the teachers to learn about the nature of the teacher development process and discuss their experiences of change in the programme?
12. Does the programme promote teachers talking with each other?
20. To what extent and in what ways do the teachers feel empowered (and not so dependent on the facilitator) by the programme?

(Bell, 1993, pp. 386-393)

Not only is the cake missing, but most of the icing is objectionable, even granted that this check list is for teacher development (in-service), not teacher preparation (pre-service) programmes. Teachers need and want subject matter knowledge; this is what is 'empowering', to use a clichéd term.

Science teacher development programmes should not be confused with encounter groups or personal growth classes. Teachers themselves are capable of their own personal development with their own friends, and in their own time. None of this should be the focus of a science teacher development programme. Much less should personal and social development be seen as on a par with professional development as the goal of teacher development programmes. Any sensible and experienced teacher educator will try to ensure that their classes are comfortable and non-threatening, that students introduce themselves and say something about their backgrounds and their reasons for being in the course. Anything much beyond this is an arrogant intrusion, and a deflection from the purpose of the course.

Before passing from this *Teacher Development* report, attention should be drawn to one not insignificant methodological matter. The LISP research on New Zealand science teacher development is based on a group of just 23 volunteers in 1990, all from Hamilton (the site of Waikato University), who were facilitated / interviewed / videoed / and developed, over a three year period. There were 19 teachers who initially volunteered for development, of these 12 completed the programme. A second group of nine teachers from one science department plus two primary teachers commenced in 1991. All participating teachers had previously been involved as researchers or subjects in Waikato LISP research.

The 'programme was designed to help the teachers implement the findings of the previous LISP projects' by developing 'teacher's ideas and beliefs about teaching, learning, the nature of science, the science curriculum, and students' (Bell, 1992, p. 3). As an aid to their development the teachers were asked to keep diaries focused on the following questions:

> What does it mean to me to be a teacher implementing the LISP findings?
>
> How do I know if I am implementing the LISP research?
>
> What do I need to be able to implement LISP research in my classroom?
>
> What are my thoughts and feelings, after sharing some or all of my journal entries with my colleagues?

One does not need to be an expert in social science methodology to suspect that the whole enterprise is a case of 'answers in search of questions'. The way the 'Study' was set up and conducted, made it highly unlikely that the constructivist principles and theory underlying the LISP research would be challenged. Maybe it was challenged by those who did not volunteer for the programme, or by those who did not complete it. We are not told why almost one-third of the first group did not complete the course, even though they initially volunteered for it. These design pitfalls are encouraged by the ethnographic, researcher-participant methodology that was, and is increasingly, used in constructivist research. There was, for instance, no control group in the Bell study. So what we can conclude about treatment effects, versus effects of no treatment, or of other treatments, is a complete mystery.

This type of research is particularly susceptible to the well-known Hawthorne effect in educational research (Adair, *et al*., 1989). The effect is named after management studies originally done in the 1920s showed that merely doing *something* with workers on a production line increased the productivity of the line. Within bounds it did not matter what was done. It was the attention, not the specific treatments, that brought about the effects. The same phenomena has been demonstrated in education research: it is often merely the doing of something with teachers or pupils, the picking them out as special and showing attention and providing materials, that results in them feeling good about the situation and increasing their productivity (however it is measured). This is in part the reason why nearly all educational experiments are successful – a researcher comes along and picks out a class, a school, a school district, and does something (it almost does not matter what) and everyone thinks it is grand and lifts their game. This is classroom placebo.

In standard Waikato research, the flattering, self-absorbed attention paid to each individual's smallest thoughts and feelings would lead to a Hawthorne effect on a scale undreamt by those conducting boring, old-fashioned social science or educational research. Consider, for instance, the following description of research in the third LISP study on learning the energy concept:

> The collaborative action-research approach involved a continuing process of observation, analysis, implementation of improvements, observation, reflection and further analysis. John, Judy and Sue, during two days spent together with the researcher, reflected on their own and each other's case studies, the researcher's analysis of them, and the researcher's trial of the preliminary package. They made constructive suggestions for John to implement in his teaching of the package. At the end of John's trial they met together again for John to review his experience. Further reflection and analysis lead to an improved package for Sue to try. This same procedure was carried out at the end of Sue's involvement with the package and subsequently also with Judy's.
>
> (Kirkwood and Carr, 1988, p. 96)

There is nothing wrong with this as collaborative pedagogy, indeed it is admirable. But what are the *research* conclusions that can be drawn from it? The research procedure invites a massive Hawthorne effect. We surely know in advance that days spent with university science education staff and a select few colleagues, which are devoted to the improvement of lessons, will be effective and highly regarded by teachers. It will not matter what is done or what is taught. The above regime would be equally efficacious in the development of Maoist cardres or Jesuit priests. There is surely no need to spend *research* money on such activity; we know the research conclusions by inexpensive armchair reflection.

Further, despite 'developing teachers understanding of the nature of science' being listed as one of the aims of the 4th LISP teacher development programme, there is no evidence of how this was done, or what the outcomes were. There is neither pretest or post-test for their 'nature of science' knowledge. Nor is there any indication of what 'development' in this area would consist of. One assumes it means becoming more of a constructivist. One obvious way that the stated aim could be achieved is to give teachers well selected books in the history and philosophy of science and have them read and discussed, preferably with people who know the subject matter. This seems not to have been done. Similarly 'understanding schools and students' was an aim, yet there is no evidence that books in the history of educational thought, or books on philosophy of education were read and analysed. These gaps are consistent with constructivist notions that knowledge just comes out of one's own head, that merely by sitting down and thinking, or discussing, we can come up with the nature of science or the purpose of education. This of course has the advantage that we can by-pass the lives of Galileo, Newton, Darwin and other scientists, and by-pass any reading in philosophy of science. We can also by-pass any reading in the history, philosophy and sociology of education. But its disadvantages should be clear.

The research report is largely transcripts of teachers' discussion. For instance one teacher comes back to the 'development meeting' and reports on their trialing of the LISP methods:

> These kids are quite uninhibited, they have a go. And they know they can have a go, it doesn't matter if it is wrong. There are no right or wrong answers and everybody has a go and that has been firmly established in the classroom. So each child's answer is just as worthy as the next one.
>
> (Bell, 1992, p. 30)

In reading this, one is reminded of Jerome Bruner's (the founder of discovery learning) lament that 'Discovery was being treated by some educators as if it were valuable in and of itself, no matter what it was a discovery of or in whose service' (Bruner, 1966, p. 15). That the above teacher's comment passes without analysis or criticism indicates the 'paradigm change' (Tobin, 1993) that constructivism is bringing to New Zealand education, a move to the U.S. model as I mentioned in the opening chapter. The project leader does note that 'eight of the teachers however still felt they had a role in giving the students information' (p. 31). This at least is encouraging, but why only eight, and did their quaint old-fashioned idea survive the 'development' course?

That such a 'study' absorbed thousands of New Zealand research dollars should be a cause for some reflection. It is simply not a study in any recognisable sense; it is a small piece of teacher activity that is set up, directed and reported by a team of university academics. It has the most limited bearing upon the type of teacher development programmes that should be made available for New Zealand teachers.

One's worry about the state of the official New Zealand science education establishment is only increased when reading in the Acknowledgements section of the report that fourteen members of the Research Advisory Committee – the who's who of science education – are thanked for their 'advice and support'. In my estimation, the five-year study seems to have been distinctly ill-advised. That this 'study' was funded by the Ministry, and advised for five years by fourteen of the country's most prominent science educators, indicates the state of New Zealand science education. Those that believe that constructivism has been beneficial for New Zealand will point to the report and rejoice; those who believe constructivism has been disastrous, will simply point to the report.

Content Knowledge and Teacher Development

Among the things teachers need from any teacher development course is knowledge of their subject and how to teach it well. As close as we get to this is a claim that the facilitators for the project 'held a view of science as asking questions about the natural and technological worlds and investigating answers to these in logical and creative ways' (Bell, 1993, p. 59). This characterisation is compatible with astrology, numerology, and most New Age-isms.

Consistent with its principles, constructivist teacher education stresses the process side of education. Education is doing things. What is done, and to what ends, is a secondary consideration. Thus at colleges of education, process is overwhelmingly stressed. A former New Zealand colleague marked a group of 35 Bachelor of Education students' practice teaching lessons. Of the 35 lesson plans, only two were concerned with knowledge outcomes in their classes. The rest were all pleasant enough activities – imagine you are a goldfish, make a goldfish collage, brainstorm goldfish – but not the things for which parents primarily send their children to school, or for which governments fund education. Only two of the lessons were concerned to inform pupils about what food goldfish ate, what temperature water they survive in, and whether they are fresh or saltwater fish.

This valuing of process skills over content mastery seems, unfortunately, to be endemic in New Zealand science education. In-service courses for teachers are overwhelmingly process orientated. Content knowledge appears not to be an important criteria for appointment as Ministry science advisers – with some advisers having no science degree at all. Advanced degrees in science are rare among College of Education science staff, even though 40 people with PhDs in science applied for a science education lectureship at the University of Auckland in 1992. And having an advanced degree in science appears to count for little in terms of selection into teacher-training programmes – if one goes on the experience of a perfectly presentable student, with Navy work experience and an honours master's degree in physics, whose application to the Auckland College of Education was turned down in 1992. The spread of 'content free' exams in schools is another manifestation of this anti subject-matter trend.[1]

While ordinary government schools are being seduced by process, élite schools maintain their focus on subject matter knowledge, thus giving their students a whole new set of advantages.

The process dominated conception of teacher development can be unfavourably contrasted with content driven programmes such as, for instance, the teacher development workshops of Nahum Kipnis the science educator at the Bakken Museum in Minneapolis. Kipnis has published a book titled *Rediscovering Optics* which is based on his Summer Institutes for Teachers. It is 200 pages of lessons, activities, discussions about Optics, its History, and How to Teach It. It is a book written for teachers which 'will help teachers deepen their understanding of optical concepts and improve their teaching techniques in a whole new way, namely, through studying the discovery of these concepts and recreating this process in the classroom' (Kipnis, 1992, p. ix. See also Kipnis 1996). There is no jargon, no hand-holding, no personal emancipation, just page after page of sensible, simple activities, and information about the major developments in the history of optics, and how using simple apparatus some of the milestone experiments can be reproduced in the classroom. This is the kind of 'empowerment' [sic] that teachers most need, and in my experience are most grateful for, but which is almost totally lacking in process-consumed New Zealand teacher development programmes.[2]

Student-Centred Teaching

Constructivism heaps additional burdens upon the already heavily laden shoulders of teachers by proposing unnecessary and unrealistic requirements said to be necessary for effective teaching.

Beverley Bell says that 'teachers need to understand what is in the mind of students – their ideas, explanations and understandings, questions, concerns, values, prior experiences and interests' (Bell, 1991, p. 160). This surely is not only intrusive, but a flight of child-centred fantasy. Teachers do not need to concern themselves, unless asked by students, with the values, concerns and interests of their students. To make teachers of 160 high school students, or 1000 university students, feel that they must so concern themselves in order to be effective teachers is not a counsel of perfection, it is just plain foolish.

Brian Simon, the professor of education at Leicester University, who wrote masterful critiques of class-based English education policy and practice, exposed the flaws in this child-centred approach to teaching when he criticised the British Plowden Report of 1967 and the educational culture that it created. He suggested that 'by focusing on the individual child ('at the heart of the educational process lies the child') ...

the Plowden Committee created a situation from which it was impossible to derive an effective pedagogy' (Simon, 1981, p. 141). And noted that 'research has shown that primary school teachers who have taken the priority of individualisation to heart [create] ... complex management problems ...[which are] far too complex and time-consuming ... for the teacher to perform' (Simon, 1981, p. 141).

However Simon's objections are not just to the obvious practical problems of child-centered pedagogy. With tiny classes, and an abundance of time, these may be overcome. His objections are deeper.

> to start from the standpoint of individual differences is to start from the wrong position. To develop effective pedagogy means starting from the standpoint of what children have in common as members of the human species; to establish the general principles of teaching and, in the light of them, to determine what modification of practice are necessary to meet specific individual needs. If all children are to be assisted to learn, to master increasingly complex tasks, to develop increasingly complex skills and abilities or mental operations, then this is an objective that schools must have in common; their task becomes the deliberate development of such skills and abilities in all their children. And this involves imparting a definite structure into the teaching, and so into the learning experiences provided for the pupils.
>
> (Simon, 1981, p.141)

Simon takes an opposite approach to teaching to that advocated in the New Zealand science curriculum documents. He is a radical, a humanitarian, and a staunch opponent of social injustice and schools' role in perpetrating it. He is refreshingly clear-headed and realistic in his pedagogical advice, saying:

> This approach, I am arguing, is the opposite of basing the educational process on the child, on his immediate interests and spontaneous activity, and providing, in theory, for a total differentiation of the learning process in the case of each individual child. This latter approach is not only undesirable in principle, it is impossible of achievement in practice.
>
> (Simon, 1981, p. 142)

He concludes his critique of Plowden-inspired, progressive education, with an observation most pertinent to the present New Zealand debate:

> new pedagogy requires carefully defined goals, structure, and adult guidance. Without this a high proportion of children, whose concepts are formed as a result of their everyday experiences, and, as a result, are often distorted and incorrectly reflect reality, will never even reach the stage where the development of higher cognitive forms of activity becomes a possibility.
>
> (Simon, 1981, p. 143)

There is a revealing, and characteristic, asymmetry between teachers and pupils in constructivist pedagogical advice. Teachers are told to find out about and understand things in the minds of their pupils – not just ideas, but values, concerns, prior experiences and so on – but are at the same time told that it is theoretically impossible to inform students of what is in their mind, namely knowledge of the subject matter of science. Pupils telling teachers something is supposedly transparent, or at least possible; teachers telling pupils something is apparently fraught with insuperable theoretical difficulties.

There are alternative models of teacher development, alternative visions of a good science teacher to that proposed by Waikato constructivists. One, F.M. Westaway's, that I mention in the Preface, has been around for over sixty years. To repeat, he says that a successful science teacher is one who:

> ... knows [his/her] own subject ... is widely read in other branches of science ... knows how to teach ... is able to express [him/her self] lucidly ... is skilful in manipulation ... is a logician ... is something of a philosopher ... is so far an historian that [he/she] can sit down with a crowd of [students] and talk to them about the personal equations, the lives, and the work of such geniuses as Galileo, Newton, Faraday and Darwin. More than all this, [he/she] is an enthusiast, full of faith in [his/her] own particular work.
>
> (Westaway, 1929, p. 3)

One might ask whether the vision of good science teaching in New Zealand has gone forward at all in the last sixty years? There is very little in any New Zealand science teacher education programmes to cultivate the capacities identified by Westaway: there is very little history, philosophy or subject matter taught in the programmes. The preoccupation with educational psychology and learning theory (about which Westaway's teacher most probably knew nothing), has pushed important substantive studies out of the teacher-education curriculum.

Women and Science

In the last two decades there has been enormous concern with the low participation of women in science. Under the heading of 'Women and Science' research has focused on a range of empirical, practical, and pedagogical matters that militate against girls' performance in science. Issues raised include teachers paying more attention to boys than girls in class, the lack of female teachers and role models in texts, the use of boys' pursuits to illustrate scientific principles, and so on. But beyond these practical and empirical matters, there have also developed feminist arguments about bias in the very nature of science and its practice which are also held responsible for girls shunning science or under-achieving in it. Constructivists have embraced both of these critiques of science – the empirical and the philosophical. The problem is that the philosophical critiques often contain an enormous amount of plain silliness, along with analyses of genuine merit and interest. The problem is that the silly parts are not distinguished from the sensible; accepting the latter seems to imply having to accept the former.

For example, consider the claims of some feminists about logic. Ruth Ginzberg, in a *Newsletter* of the American Philosophical Association, maintains that the traditional Aristotelian argument form of *modus ponens* [if P then Q, P, therefore Q] is a male patriarchal creation oppressive of women; and that more generally, formal symbolic systems are 'alien' and 'foreign' to women (Ginzberg, 1989). Another contributor to the same *Newsletter* believes that the Aristotelian syllogism is 'wonderfully fitted to hierarchical modes of thinking' because it separates the *form* of an argument from its material *content.* Women are linked to content, not form.[3] Andrea Nye in her *Words of Power: A Feminist Reading of the History of Logic* (Nye, 1990) begins by attacking Aristotle's law of excluded middle [the proposition 'P or not P' has to be true], and concludes with an argument that because Hitler used the same logic as Frege, 'logic in its final perfection is insane'!

What can be said about these claims except that they are plain stupid and demeaning of women? Presumably Hitler also washed, are we to conclude that washing is insane? The danger is that some young and impressionable students will have their brains scrambled by being given these works by feminist teachers. Further, it reinforces the image of women as irrational and illogical that most feminists (and many men) wish to erase. A logic by-pass does not promote mental health. On the contrary.

Beverley Bell at Waikato is one of many feminists who see girl's reluctance to pursue science as the result of science being 'commonly portrayed as a discipline promoting objective, rational and analytic behaviour' (Bell, 1988, p.159). It is implied that these are bad and moreover masculine traits. In contrast 'The way into learning scientific concepts and skills for many girls may be through investigating human problems and the way science and technology influence the lives of people' (Bell, 1988, p. 160).

We are not told why objectivity, rationality and analytic thinking are bad (nor are we told what they are). One might have thought that such traits were desirable, and were too often lacking in public debate, particularly by powerful men. Even if one assumes the highly debatable claim that New Zealand women are put off science by its objectivity and rationality, it is not explained why women in Europe, particularly in Eastern Europe and the former Soviet Republic, seem not to be put off science by these traits.

Not all women think that objectivity, rationality and analysis are alien to them. The prominent female philosopher of science Norette Koertge – who is also one of the very few professional philosophers of science to write on science education (Koertge, 1969) – says:

> ... if it really could be shown that patriarchal thinking not only played a crucial role in the Scientific Revolution but is also necessary for carrying out scientific inquiry as we now know it, that would constitute the strongest argument for patriarchy that I can think of.
>
> (Koertge, 1981, p. 354)

She goes on to say:

> I continue to believe that science – even white, upperclass, male-dominated science – is one of the most important allies of oppressed people.
>
> Koertge, 1981, p. 354)

Martha Nussbaum is another feminist philosopher who despairs of women abandoning objectivity as a philosophical goal. After surveying some conservative religious justifications for the oppression of women, Nussbaum observes that 'the opposition to women's equality, whether in secular or religious dress, derives support from the claim that traditional norms of objectivity are merely a parochial liberal ideology' (Nussbaum, 1994, p. 60). Contrary to those feminists attracted to the analyses of Foucault and Derrida, she says 'what the weak seem to require is a situation in which reason prevails over force, and is given special respect'. School science programmes are one important area where children can experience respect for reason prevailing over force. The banner-waving, anti-rationalist proclamations of some feminists in science education erode this possibility.

The problems with the common constructivist approach to women and science is exemplified in an article in a recent issue of the *International Journal of Science Education.* The article has the arresting title 'Humanising and Feminising School Science: Reviving Anthropomorphic and Animistic Thinking in Constructivist Science Education'. The authors, Mike Watts and Di Bentley, two influential British constructivists, are impatient with simple 'person-orientated' science for girls, in which school science is placed in a human context 'so that examples are drawn from every day life and science is portrayed as helping people, improving bodily health and caring for animals'. They want reversion to full-on animistic and anthropomorphic science in order to increase the participation of girls, saying that:

> A science in which emotions were attributed to behaviour – of atoms, molecules, forces – might make more sense for women and be a movement towards a less masculine, more feminine science.
>
> (Watts and Bentley, 1994, p. 86)

In response to the claim that this is outrageous, and takes us all, or at least women, back approximately to the fifth century B.C. (when the pre-Socratic Greek thinkers began the difficult process of understanding the world independently of spirits and inhering intelligences), the authors glibly contend that school science already is:

> ... an amalgam of 'half truths', simplifications, partial models, bent approximations, similes, analogies, anomaly-free demonstrations, cooked experiments, inexactitudes and inaccuracies.
>
> (Watts and Bentley, 1994, p. 96)

They suggest that 'diehard traditionalists' might regard 'adding an anthropomorphic flavour to school science would be including just one more calumny to the list', the constructivist teacher will see such additions 'as simply another pedagogic strategy and style to make more science more available to more pupils' (Watts and Bentley, 1994, p. 96). Nevertheless, most traditionalists would hold that however quaint it might be to attribute jealousy to atoms, to attribute it to forces really does stretch their imagination beyond its limits.

We know that there are no in-principle problems with girls learning orthodox science – there are many leading women scientists, and in European countries, particularly the formerly East European countries, women are very well represented in the ranks of university and research scientists. To some extent there are motivational and interest problems, but boys have these as well. What evidence is there that these problems might be mitigated by inclusion of animistic and anthropomorphic talk? And surely the putative cure is worse than the disease. The Scientific Revolution, and subsequently modern science, rejected animism and anthropomorphic approaches to the world. To advocate, at the end of the twentieth century, that we turn the clock back two-and-a-half thousand years, is simply outrageous, the more so if we are suggesting that the clock needs to be turned back only for women.

Consistent constructivists would say that if animism and anthropomorphism make sense to people, as surely they have and still do, then why not endorse them? There is precious little in the intellectual armoury of constructivism to avoid this conclusion. Thus constructivism leaves teachers and students susceptible to purveyors of intellectual snake-oil of all kinds.

Maori Science Education

The science education of Maori children is a serious issue in New Zealand. Pleasingly Maori participation and retention rates in school are increasing. In 1990, 15 per cent of secondary school students were Maori; the retention rate for completion of Sixth Form doubled in the decade between 1980 and 1990 (MORST, 1992, p. 20). University enrolments have significantly increased. Yet these gains were not matched by comparable increases in Maori science enrolments or technical employment. In 1990, Maori people accounted for only 3 per cent of New Zealand's scientific-technical workforce (MORST, 1992, p. 48). The proportion of Maori students graduating in physical science and engineering is lower than those completing Arts and Social Science degrees. For whatever reasons, Maori students, with some exceptions, have not participated in senior school science classes, university science degrees or the scientific-technical work force.[4]

Since the mid-1980s all New Zealand science education reports have addressed this issue. There is not much controversy about the instructional aspects of their recommendations – to make more use of Maori language, to use Maori cultural and social examples in science, to make more allowance for Maori learning styles, to put effort into having Maori scientists, science graduates, and technicians take part in school activities, and so on (MORST, 1992, p. 49). There is debate on some of these matters, in particular the extent to which some modern scientific vocabulary can be translated into Maori without loss of specific scientific meaning, and whether the recommended constructivist learning styles fit in with traditional Maori ways of learning. But these debates need not affect the present argument which is addressing the more philosophical recommendations concerning the recognition of 'a Maori body of scientific knowledge', establishing a programme to 'perpetuate and develop the body of Maori scientific knowledge', and including this body of knowledge in the science curriculum (MORST, 1992, p. 48). The debate in New Zealand on this connects with a larger international debate about multicultural science, and the kind of science education appropriate for non-Western cultures.[5]

In the last decade it has been claimed that orthodox science is culturally biased and that schools need to allow for more diverse understandings of nature to be expressed and studied. It is also claimed that science education in non-Western cultures needs to be different from that in the West; it needs to be more multicultural, if not completely ethno-scientific. The instructional part of this debate is philosophically uncontroversial: it is a concern about the overdue recognition of non-Western understandings and technologies, and about the effective, and sensitive, teaching of science to cultures that do not share the traditions and philosophy of the west. The philosophically controversial part of the debate begins when claims are made that there are a number of equally valid, and equally good sciences, and that both Western and ethnic sciences should be accorded the same status in schools, or that in certain circumstances, local ethnic science ought to replace Western science in schools.

Compatibility Between Maori Beliefs and Western Science

The *Draft Forms 1-5 Curriculum* states that 'Science education should acknowledge and value the prior knowledge, beliefs, customs, and language of students from all cultures' (Department of Education, 1989, p. 8). The *Draft* says that the Treaty of Waitangi (1840) means that science must be 'learned through a Maori frame of reference ... instead of merely fitting Maori topics into existing science curricula' (p. 8). In her discussion of the *Draft's* development, Dr Bell says that:

> With respect to science education, the Treaty has been interpreted as [needing to] provide opportunities for students to learn science in Te Reo Maori (the Maori language) and enabling the science content to be learned in the context of Maori beliefs, customs, traditions and ways of knowing.
>
> (Bell, 1990a, p. 3)

These statements make everyone feel good, but they evade the hard questions. Acknowledgement of traditional beliefs is one thing, valuing – at least in the sense of 'endorsing' or 'agreeing with' – is altogether another thing. Surely no one is being asked to value, in the sense of agree with, female circumcision, throwing widows on to their husband's funeral pyres, systematic sexual discrimination, deadly hygine practices, and scores of other such well established, and abhorrent, traditional beliefs and practices? Why should traditional scientific beliefs be *in principle* valued? We know that Western science is simply incompatible with many deeply and dearly held cultural and other beliefs, frames of reference, and ways of knowing. This is the case for both traditional and Western society – fundamentalist Christian Creation Science, and most forms of New Ageism, being the obvious cases of the latter incompatibility. Incompatibility between science and culture occurs at all levels, from specific beliefs, to frames of reference for beliefs, to epistemological theory, and to the social organisation of science. There is standardly a difference between the cosmology, world view and methodology of Western science, and the corresponding aspects of traditional, or indigenous, science.

At the specific level there is usually an incompatibility between Western scientific and traditional beliefs about phenomena – for example, the causes of malaria or other diseases. At the level of frames of reference, there is also incompatibility – for example, traditional knowledge systems frequently have animistic, anthropomorphic, teleological and idealistic presuppositions; Western science has, after centuries of debate, abandoned all of these. At the level of epistemology there is incompatibility – for example, in many traditional knowledge systems, what makes something knowledge is *just* its agreement with tradition or with the edict of an authority figure; Western science has abandoned this in favour of some form of experimentalist epistemology. Finally, there is incompatibility at the level of organisation – traditional knowledge systems are usually closed and authority bound; Western science, for all its faults, is in principle open to debate and change, and authority *per se* counts for almost naught, especially in the long term.

Robert Merton provided the classic analysis of the *structural* presuppositions of Western science in his 1942 paper, 'The Normative Structure of Science'. There he states:

> Four sets of institutional imperatives – universalism, communism, disinterestedness, organised scepticism – are taken to comprise the ethos of modern science.
>
> (Merton, 1942/1973, p. 270)

Elaborating this claim, he says that:

> *Universalism,* means that the acceptance or rejection of claims entering the lists of science is not to depend on the personal or social attributes of their protagonist; his race, nationality, religion, class, or personal qualities. (p. 270)
>
> *Communism,* means that the substantive findings of science are a product of social collaboration and are assigned to the community. ... Secrecy is the antithesis of this norm; full and open communication its enactment. (p. 273)
>
> *Disinterestedness,* means that the institution of science has in-built policing devices stemming from its commitment to verifiability and collegial checking. (p. 276)
>
> *Organised Scepticism* refers to both a methodological and an institutional mandate. It involves the temporary suspension of judgement and the detached scrutiny of beliefs in terms of empirical and logical criteria. ... [thus] in modern totalitarian society, anti-rationalism and the centralisation of institutional control both serve to limit the scope provided for scientific activity. (p. 277)

The Mertonian thesis is not without its problems, and it does require elaboration. But it does correctly identify the degree to which there is incompatibility between Western science and those traditional communities, including Maori, whose knowledge systems are embedded in societies lacking the 'ethos' of Western science. The 1992 MORST report indeed recognises this when, after recommending the setting up of a programme to develop Maori knowledge, it warns that:

> Care would need to be taken in the setting up of such a programme as many holders of Maori scientific knowledge will wish to ensure that control is retained over the transmission and appropriate use of that knowledge.
>
> (MORST, 1992, p. 49)

Australian aboriginals are likewise rightly concerned that their 'special' knowledge not be divulged and broadcast to all and sundry. In their communities, special knowledge is intimately connected with social position, group structure and ritual. If the wrong persons, especially women, even inadvertently see particular paintings, or ceremonies, that embody 'special' knowledge, they are severely punished. It is simply a category mistake to think that most traditional knowledge can be expropriated, taught in classrooms and elaborated in textbooks. But this fact means that traditional knowledge is altogether a different thing from Western scientific knowledge, and to call it 'science' is perhaps to create misunderstanding.

Robin Horton in his much-discussed study of African and Western science drew attention to the epistemological and structural incompatibilities mentioned above. After outlining points of similarity between African and Western science, he concluded by drawing attention to the deep differences:

> The key difference is a very simple one. It is that in traditional cultures there is no developed awareness of alternatives to the established body of theoretical tenets; whereas in scientifically orientated cultures, such an awareness is highly developed. It is this difference we refer to when we say that traditional cultures are 'closed' and scientifically oriented cultures are 'open'. (Horton, 1971, p. 153)

Characteristically, the New Zealand curriculum documents do not spell out what is meant by key terms such as ‘valuing’. Nor is the pressing question addressed of how to teach scientific accounts of, for instance, human evolution in the context of Maori beliefs about Maori and human origins. The two are plainly incompatible. Intelligent discussion about what is to be done in schools must begin by recognising this incompatibility. The Treaty of Waitangi is as irrelevant as a Vatican decree, or a resolution of the Communist Party’s Central Committee, to the question of whether or not particular cultural beliefs and frames of reference are compatible with either the findings, or the processes, of modern science. To pretend otherwise is to irresponsibly put one’s, or worse still children’s, head in the intellectual sand. The situation is not unlike that in parts of the U.S. where one state was proposing to legislate the value of π to be 3.0, and that led John Kemeny to remark that:

> I had a horrible nightmare one night in Washington: the House of Representatives, by a vote of 215 to 197, had repealed Newton’s Law of Gravitation.
>
> (Marx, 1994, p. 55)

The 1988 version of the *Draft Forms 1-5 Syllabus* begins with the warm and fuzzy statement that:

> Different cultures have their own forms of scientific knowledge. This syllabus helps students to consider how culture affects science, and how different societies have alternative explanations of things and events. (p. 5)

Once more this is a collection of truisms masked by a complete evasion of the central issue. When curriculum framers say that a nation’s science curriculum will ‘help students to consider ...’ this vital issue, they should spell out what is meant by ‘consider’. We all know that different cultures have different forms of knowledge and alternative systems of explanations. This is the stuff of anthropological investigation. An *anthropology* course rightly considers the full range of interesting and bewildering views that different cultures have about the workings of nature. The pressing question for deciding the content of a *science* course is which of these different systems best captures the nature of reality and give the most reliable guidance for prediction and control of events. In terms of overall, systematic understanding of nature, Western science has no equal. This truth should not be fudged in the way it is in the 1988 *Draft.*

This fact does raise the question of whether intellectually, and politically, traditional bodies of knowledge about nature should indeed be labelled ‘science’, as all New Zealand curriculum documents so label Maori science. This may be both an intellectual and political mistake. Intellectually, to label something ‘science’ suggests it shares enough common features with mainstream science to warrant the appellation; that there is enough of a ‘family resemblance’ in Wittgenstein’s terms, to justify the same generic title. This matter was fought out in the US during the 1981 Creation Science trial in Little Rock, Arkansas where the philosopher Michael Ruse argued that fundamentalist Creation Science simply was not science in any recognisable sense of the term.[6] This argument, which will not detain us here, does hinge upon definitions of science which are notoriously hard to establish.[7] Suffice to say, as I have indicated above, that there are enough significant *differences* in beliefs, world views, methodology, purposes, and organisation between mainstream and Maori science as to give pause to calling both ‘Science’.

There is a political dimension to this terminological dispute. The liberal, and dominant New Zealand approach, is that it is good politics to call indigenous knowledge systems ‘science’ because this is honorific, egalitarian, and bicultural. As the *Draft* says, ‘Different cultures have their own forms of scientific knowledge’. This may be good short-term politics, but it is probably bad long-term politics. Once Maori knowledge is labelled ‘science’, once it is put in the same ring as Western science, then political correctness demands that we give it equality with Western science.[8] This position is expressed clearly by Graham Smith of the University of Auckland’s Education Department, who maintains that:

> There is a need to struggle to assert the equal validity of Maori knowledge and frameworks and conversely to critically engage ideologies which reify Western knowledge [science] as being superior, more scientific, and therefore more legitimate.
>
> (Smith, 1992, p. 7)

However, if Western and Maori sciences are in the same ring, if they can be compared, then sooner or later most people, Pakeha and Maori, are going to have to recognise that Western science is far superior. Maori science has manifestly not given us an understanding of the atom, planetary motion, the evolution of species, heart disease, and so on. Nor has it produced everyday technologies such as telephones, X-ray machines, aeroplanes and the like. To put Western science and Maori knowledge in the same ring is to invite the latter’s humiliation. This can only have deleterious educational and cultural effects for Maori children.

The consequence of such ‘different but equal’ views, if taken seriously, is to mitigate against Maori children learning modern scientific knowledge – after all, if Western science is not superior, why should students be taught it. However there is a genuine question about how seriously such views are taken. It is reasonably said that if you want to know what someone’s beliefs amount to, you should look at what they do about them. When this is done, proclamations of ‘equal but different’ standardly turn out to be hand waving exercises. The proponents of such views often deny them in their own practice. They use Western medicine, modern technology, fly in aeroplanes, and are dependent upon food supplies grown, harvested, transported and cooked by modern technology. In practice there is no question of equal validity, it is only in rhetoric that equality is claimed. Provided the rhetoric does not affect anything, it is harmless. But unfortunately educational rhetoric often does affect policy and practice.

In parts of the U.S. this rhetoric resulted in equal time in the science programme for Creation Science. This seems an inescapable consequence of the ‘equal validity’ position advocated by Graham Smith and others. If taken seriously, it does imply that science courses be split between orthodox and Maori science (and why not Christian Science and Creation Science?), with teachers saying, in the words of the *Draft Forms 1-5 Syllabus*, that ‘different societies have alternative explanations of things and events’ and we cannot say which explanations are better. The intellectual victims of this programme will be the children, Maori or otherwise, who leave school without an appreciation of the distinctive and unequalled achievements of Western science. The practical victims of this programme will be all New Zealanders. Having students master just orthodox science is demonstrably difficult enough, to have them master two sciences is absurd and will weaken the nation’s scientific competence. The resulting economic, environmental, health and social consequences will affect everyone.

Perhaps it is better politically to simply say that Western science and indigenous knowledge are in *different* categories of human endeavour. This is intellectually respectable – there are lots of perfectly good ways of thinking that are not scientific – and it means that unnecessary and harmful comparisons need not be made between mainstream science and traditional knowledge systems. It has the obvious cultural advantage that Maori children can freely and rigorously learn science without compromising their Maori identity. The botanist Murray Parson has opted for this alternative, suggesting the Maori term *matauranga* be used to describe Maori natural knowledge, as this term makes no assumptions about how scientific, in the Western sense, that knowledge is, and it recognises that science and *matauranga* do not seek to do the same thing (Dickison 1994). The genuine need to have New Zealanders appreciate Maori cultural achievements can be achieved in social science programmes, or even in science programmes provided the unrealistic 'equal validity' claim is dropped. Appreciation of Maori achievement simply does not require this.

More generally everyone can benefit from learning about the technical and intellectual achievements of non-Western cultures.[9] But in schools, where the mastery of the basics of Western culture – reading, writing and arithmetic, to begin with – is so poor, there are genuine issues of how much time can be devoted to mastering the complex achievements of other cultures, and whether such 'mastery' is at the expense of trivialising those achievements. There is a great danger here of children falling between cultural stools.

How Natural is Science?

The New Zealand 1992 *Draft Science in the National Curriculum* repeats a common constructivist position, namely:

> The science curriculum needs to recognise that science is a universal discipline and acknowledge the contribution that different cultural perspectives make to the development of understanding in science.
>
> (p. 7)

This statement is repeated in the 1993 *Science in the New Zealand Curriculum* (p. 7). The earlier 1988 *Draft Forms 1-5 Science Curriculum*, stated this idea as follows:

> People are scientists. They investigate the kinds of fish in a stream ... hypothesise about toffee not setting, ponder on the question of what makes a rainbow.
>
> (p. 6).

This assumption of the naturalness of science is crucial to most facets of constructivist pedagogy and curriculum development. Constructivists hold a seamless web view of science: science is going on whenever people scratch their head and wonder about the world. Everyone does science. Thus Roger Osborne, at Waikato, used the term 'children's science' to refer to children's ideas about the world (Osborne, 1980); and one science textbook states that 'whenever you observe the world around you, you are acting like a scientist' (Hurd, *et al*., 1991, p. 6, quoted in Cromer 1993, p. 20). Many constructivists cite George Kelly, who held that 'everyone is a scientist' (Kelly, 1955) to support such egalitarian views.

Constructivism proposes a facile continuity between the activity of children and the activity of scientists. It suggests that children are proto-scientists, and scientists are somewhat older children. This *continuity* thesis allows the 1989 *Draft Forms 1-5 Syllabus* to claim that 'we are all scientists' (Ministry of Education, 1989, p. 5), and the 1992 *Science in the National Curriculum Draft* to say that science is an activity 'that can be carried out by all people as part of their everyday life' (Ministry of Education, 1992, p. 8). But the warm, fuzzy glow of the continuity thesis is bought at a price: If we are all scientists, and if science is something that everybody is already doing, why bother with science education and why bother with funding science teachers?

The new day of universalism, is really just Hegel's dark night wherein all cows are black. If the thinking of each individual and every culture is scientific, then we have to invent a new set of words to mark the legitimate distinctions between orthodox scientific thinking and the myriad forms of religious, poetic, artistic, infantile, primitive, magical and self-centred thought that is common in all cultures, including advanced Western culture. Constructivist's warm universalism gives support to such corruptions of language as Mary Eddy's Christian Science, fundamentalist Creation Science, and Stalin's Proletarian Science – after all they are all ways of wondering about the world.

Alan Cromer, in his excellent book *Uncommon Sense,* counters this universalist credo, with the simple observation that:

> Every astrologer, homoeopathist, Tarot-card reader, witch doctor, or psychoanalyst makes observations and works according to a predetermined order or plan. To call such work scientific, or even prescientific, is to miss the essential meaning of science. These non-scientific systems are tradition bound and self-referential, working within their own closed system of ideas ... Such non-scientific systems have been around since Paleolithic times.
>
> (Cromer, 1993, p. 20)

Orthodox Western scientific thinking had its origins in pre-Socratic Greek thought, where it was surrounded by advanced and civilised cultures which nevertheless did not get near to scientific thinking. For two thousand years this minority scientific tradition did not flourish, neither in the West nor elsewhere. This was so despite there being countless people of great genius (think of the achievements of Thomas Aquinas or Michaelangelo for instance), and magnificent technological achievements (think of the medieval cathedrals or the Taj Mahal). In sixteenth century Europe a complex set of personal, social and historic circumstances led to the revival of the dormant scientific tradition and gave birth to the Scientific Revolution, so associated with the intellectual achievements of Galileo, Boyle, Huygens, and above all Isaac Newton.[10]

Science is not just a collection of ideas about the world, it is also a way of thinking and evaluating claims. Neither the ideas, nor the methods, are natural: if they were, we would have had modern science thousands of years before it emerged, and all cultures would share the scientific approach to analysis of the world.[11] It is not just the discoveries of science that have to be learned and taught, it is the very outlook, procedures and methodology of science that have to be learned: these do not come naturally. Peter Slezak has observed that:

> The values extolled and exemplified in the works of Bronowski, Russell, Einstein and the Western scientific tradition inherited from the Milesians is only as robust as our capacity to impart it to the next generation. This is both the threat posed by current sociological doctrines and the challenge for science educators.
>
> (Slezak, 1994a, p. 291)

Universalism in Epistemology

Western science is universalist in its epistemology. It is in this sense that science is universal, not the sense of universality that occurs in the New Zealand science curriculum. In 1922 George Sarton, the founding editor of *Isis*, the first history of science journal, said:

> The development of knowledge knows no political or racial boundaries. It is the only development which is truly international. If we wish to bring the peoples of the earth together should we not draw their attention to the treasures which are their common heirlooms, to the things which unite them? The history of the quest for truth is the history of no single nation; it is the history of mankind.
>
> (Pyenson, 1992, p. 96).

Universalists regard science as an intellectual activity whose truth-finding goal is not, in principle, affected by national, class, racial or other differences: science transcends human differences. Science is a hard-won vehicle for common engagement across cultures, religions and races. This universalist view recognises that while aspects of culture do influence science, nevertheless cultural considerations do not determine the truth claims of science.

Max Planck was one of many who shared this universalist creed. He regarded his formula for the distribution of energy in a heated cavity as something 'which will necessarily retain its importance for all times and cultures, even for nonterrestrial and nonhuman ones' (Heilbron, 1986, p. 6). This is a statement of the widest possible independence of scientific truth from all human and nonhuman interests. The attitude was shared by the French physicist-philosopher Pierre Duhem, who was concerned to trace the influence upon science of different national characteristics. However, having undertaken this in various works, including one on German science written during France's darkest days in the Great War when the German army was almost on the outskirts of Paris, he went on to say:

> Considered under its perfect form, science ought to be absolutely impersonal. Since no discovery in it would bear the signature of its author, neither would anything allow one to say in what land the discovery saw the light of day ... there is no trace of the English mind in Newton, nothing of the German in the work of Gauss or Helmholtz. In such works one no longer divines the genius of this or that nation, but only the genius of humanity.
>
> (Duhem, 1916/1991, p. 80)

The core universalist idea is that the material world ultimately judges the adequacy of our accounts of it. Scientists propose, but ultimately, after debate, negotiation and all the rest, it is the world that disposes. The character of the natural world is unrelated to human interest, culture, religion, race or sex. Ultimately the concept is judged by the object, not the other way around. Just as volcanic eruptions are indifferent to the race or sex of those in the vicinity, and kill whites, blacks, men, women, believers, nonbelievers equally, so also the science of volcanoes is the same for all. For the universalist, vulcanology is, of course, a human construction (this frequently cited constructivist insight is just a tautology), with negotiated rules of evidence and justification, but it is the behaviour of volcanoes that finally determines the adequacy of our vulcanology.

Worldviews and Science Education

There is a legitimate concern about the effect of science teaching on the world views of both western students, and students from traditional cultures. This is an important concern, but we may worry too much about it. Eminent scientists have included idealists and deeply religious Christians, Jews, Muslims and Hindus; others have been materialists and militantly anti-religious. Isaac Newton was an unconventional Christian whose library contained 138 well-read books on alchemy; Michael Faraday was a devout member of the obscure Victorian Sandemanian sect; Darwin was an atheist whilst Lyell, his acknowledged inspirer, was a theist; the physicist Pierre Duhem was a devout Roman Catholic while his contemporary, the equally eminent physicist and philosopher, Ernst Mach, was an atheist, a socialist and a positivist; the physics Nobel laureates Philipp Lenard and Johannes Stark were Nazis and anti-Semites, while their contemporary laureate, Albert Einstein, was a Jewish anti-Nazi; the mathematician Ramanujan said daily prayers to the Goddess Namagiri, the consort of the Hindu lion-god Narasimba; Erwin Schrödinger was a non-Christian idealist who regarded mind and matter as equivalent and who chose to end one of his books with the equation: 'ATHMAN = BRAHMAN (the personal self equals the omnipresent, all-comprehending eternal self)'.

That this kaleidoscope of beliefs has coexisted with the most sophisticated scientific practice suggests some caution in pronouncing what worldviews are and are not compatible with education in mainstream science. There may be limits, but the limits seem wider than might initially be thought. The human mind is complex, internal coherence among beliefs is rarely attained, and the basic beliefs are seldom stable. But recognising all of this, one can still delineate epistemological and ontological assumptions (world views) that are more or less scientific, and those that are more or less anti-scientific. Science teachers should aim at cultivating the former and discouraging the latter. Their success will depend almost entirely upon social and cultural factors outside of their control.

Science and Social Interests

Constructivists repeatedly say that science reflects human interests. In the words of Beverley Bell, 'science and scientists do not exist in a social vacuum ... science is shaped by society ... science, society and technology are interactive ... science is not detached from the lives of people' (Bell, 1988, p. 159). This is hardly novel or controversial. Science has frequently been conducted for non-cognitive purposes. Identification of farm boundaries in the flooded Nile delta triggered major discoveries in geometry, people's interest in curing illness has resulted in medical knowledge, canal building in England was a spur for the science of stratigraphy and so on. But science has also been conducted to serve cognitive interests, that is, simply to find out how the world is. Galileo's pendulum investigations were not carried out in order to tell the time; Newton's *Principia* was not written to better navigate ships. As Arthur Koestler wrote in *The Sleepwalkers*:

> The aim of those men who created the Scientific Revolution was not the conquest of Nature, but the understanding of Nature. The revolution in technology was an unexpected by-product.
>
> (quoted in Marx, 1994, p. 78)

The philosophical issue is not whether science serves interests. Of course it does. The issue is whether or not serving interests compromises the intellectual integrity of science. Francis Bacon in his 1620 discussion of the Idols of the Mind (Aphorisms 39-45 of *Novum Organum*) stated as well as anyone the dangers that interest presents to understanding. On this issue his Aphorism 44 is worth quoting:

> The human understanding is no dry light, but receives an infusion from the will and affections; whence proceed sciences which may be called sciences as one would. For what a man had rather were true he more readily believes. Therefore he rejects difficult things from impatience of research; sober things, because they narrow hope; the deeper things of nature, from superstition; the light of experience, from arrogance and pride, less his mind should seem to be occupied with things mean and transitory; things not commonly believed, out of deference to the opinion of the vulgar. Numberless in short are the ways, and sometimes imperceptible, in which the affections colour and infect the understanding.

Bacon drew attention to the Idols of the Mind in order to avoid their influence. He, and most sensible people ever since, are aware that self interest, national interest, class interest, racial interest, gender interest, party interest and all the rest, affect what people believe. Constructivists, and postmodernists more generally, assert that all knowledge is irrevocably compromised by interest. This is a much more controversial matter. Those who believe, as did the Nazis and Stalin, that interests fundamentally compromise science, are generally led to some version of the multi-science thesis: Western science is just one science (white, male and middle class) among many equally good and valid sciences – feminist, working class, black, ethnic, Muslim and so on. The Nazis held this view and dismissed relativity theory on the grounds of its Jewishness.

In 1936, at an anniversary of the University of Heidelberg, Dr Berhard Rust, the Nazi Minister of Science and Education, stated that:

> The old idea of science based on the sovereign right of abstract intellectual endeavour has gone forever. The new science is quite the opposite of uncontrolled search for truth which has been the ideal heretofore. The true freedom of science is to support the state and share its destiny and make the search for truth subservient to this aim.
>
> (Taylor, 1941, p. 39)

Good history of science, and more recently good sociology of science, have documented many cases where interest, broadly construed, has deformed scientific research. However, we can only complain about this if we maintain some ideal of objective knowledge to which science is aspiring. If science is accepted as just the pursuit of interest, then Nazi science, Stalinist science, Creation science, Cyril Burt's fraudulent IQ science, and all the others, cannot be criticised for letting interest interfere with science. In New Zealand the production of biased, special-interest-serving environmental impact statements has been roundly criticised. They are rightly seen as the prostitution of science. How constructivists can complain about this needs to be explained. If non-cognitive interests cannot be eliminated, and if manipulation of data does serve those interests, then, for constructivists, that seems to count as successful science.

For fifty years the Japanese government has denied second World War war crimes – the murder of millions of Chinese, the enslavement of thousands of 'comfort' women etc. The courageous few Japanese who have struggled to proclaim the truth, and to have school text books reflect the truth, and the victims of Japanese atrocities, would be astonished if told by comfortable Western academics that there is no truth to ascertain, there is only interest to be advanced. The government's interests are certainly bigger than theirs. The interests of ruling groups are always going to be more powerful than the interests of marginalised groups. Why constructivism is seen as a progressive and liberating doctrine, when it essentially says that might is right, is a complete mystery.

One can say that 'bias cannot be eliminated' – as Beverley Bell puts it in one publication (Bell, 1988, p. 159) – and that the criticism of special interest sciences will always be from the standpoint of other interests. This makes academic criticism just a case of who has the biggest, loudest, or best organised and richly funded interest. Not a welcome conclusion – particularly for the weak and powerless. Alan Ryan noted this when he said:

> It is, for instance, pretty suicidal for embattled minorities to embrace Michel Foucault, let alone Jacques Derrida. The minority view was always that power could be undermined by truth ... Once you read Foucault as saying that truth is simply an effect of power, you've had it ... But American departments of literature, history, and sociology contain large numbers of self-described leftists who have confused radical doubts about objectivity with political radicalism, and are in a mess.
>
> (Gross and Levitt, 1994, p. 82)

Knowledge Without Conceptual Structure

Science in the New Zealand Curriculum is remarkable for its neglect of the conceptual structure of science. There is almost no indication that in learning science, children are learning something that is conceptually ordered and interrrelated. As the outstanding features of modern science are its conceptual structure and the manner in which concepts (energy, entropy, force, evolution etc.) are related across different fields of investigation, this gross neglect is astonishing. This is the more so because constructivists stress the learning of concepts in science rather than learning facts or information.

The 'conceptual change' model of George Posner, Kenneth Strike and Peter Hewson, and the 'generative learning' model of Roger Osborne and Melvin Wittrock are repeatedly cited in constructivist research, and they are both concerned with the conditions for conceptual change and development in pupils. Given this, one would have expected more attention to the conceptual structure of the subject matter that pupils are supposed to grasp. Besides which we know that the learning of conceptually ordered and interrelated material is both easier, more satisfying, and more efficacious or generative, than the learning of scrambled and unrelated subject matter. Teachers ever since Plato, and presumably before, have been aware of this. David Ausubel gave it contemporary empirical validation (Ausubel, 1963).

The neglect of subject matter structure in the curriculum is another outcome of the constructivist focus on the learner rather than the subject being learned. It is something that naturally follows when ‘making sense of’ is substituted for ‘learning about’ in the aims of the curriculum. Students can ‘make sense’ of the living world in any variety of ways, some structured others not structured, some scientific others not scientific. So, for instance, the Achievement Objectives at Level Three in the ‘Making Sense of the Physical World’ strand (old style physics) specify that students should be able to ‘investigate *their* ideas about some commonly experienced physical phenomena to develop *their* understanding of those phenomena’ (p. 76, emphasis added). The curriculum does not direct them to investigate scientific ideas about motion or evaporation, but their ideas about these subjects.

Whatever the drawbacks were of the 1960s U.S. curricular programmes, one of their strengths was the widespread recognition that learning in science involved the mastery of concepts, and accordingly effort was put into selecting, ordering and prioritising scientific concepts in the curriculum. The resulting curricula were titled structure-of-the-discipline curricula. One commentator on the 1960s reforms drew attention to this feature:

> In each of the experimental science curriculum studies an effort was made to find an organisational basis for the subject matter which would provide an internal logic and a coherent structure for the course. Such a basis would need to have meaning for high school students as well as for scientists. Within the sciences there are unifying ‘conceptual schemes’ serving to integrate the knowledge of the field as well as to provide a focus for scientific investigation. These schemes were identified and used to map out the curriculum territory for each of the new science courses. Not only do the schemes provide a means for organising a course but they suggest how a student should pattern his learning. ... For the curriculum developer conceptual schemes provide a means for organising individual courses as well as entire science curriculum from elementary through high school.
>
> (Hurd, 1969, p. 77)

Jerome Bruner, the Harvard psychologist and convenor of the famous 1959 Woods Hole conference that formulated the theoretical underpinnings of the U.S. curriculum reforms of the 1960s,[12] said in *The Process of Education* (the book that publicised the conference deliberations), that:

> ... the curriculum of a subject should be determined by the most fundamental understanding that can be achieved of the underlying principles that give structure to that subject. Teaching specific topics or skills without making clear their context in the broader fundamental structure of a field of knowledge is uneconomical.
>
> (Bruner, 1960, p. 31)

Joseph Schwab, the Chicago educationalist, philosopher and driving force behind the Biological Science Curriculum Study, was one of the most eloquent and forceful advocates of the importance of conceptual structure in the science curriculum. He wrote a seminal essay on the subject – ‘The Concept of the Structure of a Discipline' – in 1962. In another influential essay, on inquiry learning and its connection to conceptual structure, he remarked:

> ... enquiry has its origin in a conceptual structure ... It is this conceptual structure through which we are able to formulate a telling question. It is through the telling question that we know what data to seek and what experiments to perform to get those data. Once the data are in hand, the same conceptual structure tells us how to interpret them, what to make of them by way of knowledge. Finally, the knowledge itself is formulated in terms provided by the same conception.
>
> (Schwab, 1964, p. 12)

This tradition of research concerned itself with the structure of science, and how it relates to the structure of children's cognition, the learning of science, and to the structure of the curriculum. They were concerned with conceptual priorities and progression, with specifying the key concepts in the learning areas and the logical ordering of these concepts. They were also concerned with psychological ordering and the pupil's cognitive structure. The U.S. curriculum planners put a lot of effort into these issues, and they utilised immense bodies of research – see for instance David Ausubel (1964), contributors to Elam (1964), and the review by Phillips and Kelly (1975).

This research and concern is absent from the New Zealand science curriculum. Although the curriculum in its opening pages states that 'Science is both a process of enquiry and a body of knowledge; it is an integrated discipline' (p. 14), the curriculum proceeds to give no, or little, indication that there is an organised body of concepts to be learned in science.

Hence if one follows through the Achievement Objectives for the topic that in old-speak would have been called electro-magnetism, we find:

LEVEL	ACHIEVEMENT OBJECTIVE	POSSIBLE LEARNING EXPERIENCE	POSSIBLE ASSESSMENT EXAMPLE
1	share and clarify ideas about magnetism	making a magnetic maze	classify objects attracted and not attracted to a magnet
2	investigate ideas about magnetism and electricity	construct simple circuits to make light bulbs glow; measure the strength of a magnet using paper clips	identify uses for magnets around the home
3	investigate and describe their ideas about simple electric circuits	taking a torch apart to find how the bulb is connected to the battery	students construct their own torch and compare it to a commercial one
4	investigate and offer explanations for electric current	work in groups to find a simple circuit to light a model house	find out about the invention of the telephone
5	carry out simple practical investigations into electro-magnets, and electric circuits	work as part of a group to construct a relay circuit for switching on an electric motor.	students construct electro-magnets
6	investigate patterns in	set up circuits to measure	describe relationships

	voltage and current phenomena	voltage and current; find out how a television works	between V and I readings obtained in group work
7	understand the principles involved in microwave ovens and cellular phones	analyse the heating effects of a microwave oven at different power settings	determine which battery is best to use in a 'walkman'
8	clarify ideas on the use of energy in compact disc players	design a model magnetic door lock; observe a Geiger counter response to alpha, beta and gamma rays	present a seminar on the operation of a fluorescent tube; debate nuclear testing in the South Pacific

There is precious little guidance here for thirteen years of teaching about electricity and magnetism; so little guidance as to make one doubt the point of all the time and effort that went into the preparation of the document. There is a lot of clarifying, sharing, making and investigating, but not much learned. There is a lot of activity, but precious little conceptual development. Complex conceptual matters are inserted in an almost haphazard way, with little attention to the intellectual prerequisites required. For example, at Level 7 (the penultimate year of school, age 16-17 years), the microwave oven appears, but electromagnetic waves have not previously appeared, much less have cathodes, anodes, electron resonance – all of which are involved in understanding the microwave. One can only guess at what, for average pupils, 'clarifying ideas on the use of energy in compact disc players' might result in, or what a 'seminar on the operation of a fluorescent tube' would be, or what there is to debate about French nuclear testing in the South Pacific. For the very brightest and most motivated, who come from supportive and well-provided (rich) homes, such clarifying and debating may be instructive; for the bulk of pupils, time is surely going to be better spent in learning some of the essentials of the electromagnetic spectrum, radioactivity and nuclear chemistry.

The New Zealand science curriculum repeats many of the features of some of the earlier U.S. Science Process Curricula, such as the American Association for the Advancement of Science's 'Science – A Process Approach'. One weakness with these curricula, in contrast with their structure-of-the-discipline contemporaries, were their lack of structure, and their underestimation of orderly conceptual development. One critic at the time, Myron Atkin, made a comment that could equally be made of the New Zealand curriculum:

> A basic flaw in the process is the apparent assumption that science is a sort of commonsensical activity, and that the appropriate 'skills' are the primary ingredients in doing productive work. There seems to be no explicit recognition of the powerful role of the conceptual frames of reference within which scientists and children operate and to which they are firmly bound. These general views of the physical world demand careful nurture ... by a variety of means.
>
> (Atkin, 1968, quoted in Glass, 1970, p. 20)

This point was made almost one century ago by John Dewey when he addressed the question of what content to include in a science syllabus. He said that:

> One method is the scrappy one of picking up isolated materials just because they happen to be familiar objects within the pupil's experience, and of merely extending and deepening the range of pupil's familiarity, and then passing on to something else. No amount of this will make an introduction to education, to say nothing of science, for an introduction leads or draws into a subject, while this method never, save by accident, gets the pupil within range of the problems and explanatory methods of science.
>
> (Dewey, 1916, quoted in Hurd, 1969, p. 37)

Professor Geoffrey Howson, of the University of Southhampton, has identified comparable problems with the new constructivist-inspired, New Zealand Mathematics Curriculum, about which he says:

> In general, then, I welcome the emphasis to be found on activity and on contextualisation so far as it counteracts excessive tendencies in the past towards formalisation. However, simply loading a curriculum with 'ings' (for example on p. 45 we have learning, exploring, using, extending, investigating, relating, talking, saying, inventing, developing, maintaining, devising, solving, writing, finding, ...) does not answer any real pedagogical or curriculum problem. ... It is right to fight against the view that a curriculum is simply a list of topics to be learned. However, an attempt to teach mathematics solely through activity is bound to fail, if only because students have to be helped to construct a framework with reference to which they can organise knowledge. ... They have to be helped to identify key 'kernels', definitions, notations and conventions, results and procedures, which they must commit to memory or know where they can be found. These are the bricks which they will employ, together with the 'ings', to create new kernels.
>
> (Howson, 1994, p. 18)

Hard-pressed teachers might reasonably expect both the Science and the Mathematics documents to identify and itemise these conceptual kernels, and to place them accordingly in the attainment targets for different levels.

A Curriculum Without Direction

Apart from the lack of conceptual structure, there is a lack of pedagogical, or programming, structure in the curriculum document. Despite the formidable apparatus of Achievement Objectives and the like, there is a significant element of 'teach what you want' in the curriculum. It ambitiously adopts a *laissez faire* approach to specifying scientific content. The *Science in the New Zealand Curriculum* document says that:

> This curriculum statement in science provides the framework for planning and making decisions about a school's science programme. Teachers, with the support of their school community, will use it to develop their school science scheme.
>
> (Ministry of Education, 1993, p. 21)

Thus, for instance in 'Making Sense of the Physical World' [Physics in old-speak], there are eight levels of Achievement Objectives specified, with each level having up to four sub-levels. These objectives specify the skills, attitudes and knowledge that students should achieve at the different levels (which are in turn approximately related to school grade levels). For each mandatory Achievement Objective, the document gives *Possible* Learning Experiences, and *Possible* Assessment Examples. There is no stipulation about the learning experiences or the assessment. It is said that this ‘will result in each school providing a unique science programme that recognises the particular character of their student population ...’ (Ministry of Education, 1993, p. 21). This statement is either hyperbole or just stupid.

Are New Zealand school populations *so* variable that *unique* science programmes have to be constructed? And why should programmes be tailored to student populations, even if it could be shown that there were identifiable and relevant differences between schools? It is not specified just what variability in student population teachers should adjust their science programmes for:gender? Race? Religion? Class? None of these seem appropriate, indeed they are most inappropriate. Perhaps intelligence or ability is meant, but this is certainly not stated.[13]

This seemingly progressive idea of tailoring education to student differences or interests is frequently a mask for schools’ reproduction of social inequality. In the U.S. the ‘different education for different children’ doctrine, was, and often still is, used to justify special programmes for Afro-Americans; in South Africa it was the basis of apartheid schooling; in Germany and Russia it was used to discriminate against Jews; in England, Australia and New Zealand it legitimated putting girls into cooking and needlework classes; and universally it has been used to justify the provision of inferior education for working class children. The argument is that children from Brixton, Redfern, South Los Angeles or South Auckland are different from middle-class children and thus schools should not expect them to master algebra, read Jane Austen, or spell correctly.

Even if this standard discriminatory function of the ‘different schooling for different children’ is avoided, there are still practical problems with encouraging schools to craft ‘unique’ programmes of work for pupils. What happens when children change schools? How can fair comparative exams for university entrance or scholarships, be staged unless they are ‘content free’ exams? And so on.

To say that the curriculum is only meant to be suggestive, and that teachers will determine their own programmes, might sound progressive and in tune with the egalitarian times, but it is just professionally irresponsible. There is very little guidance in the document. At crucial points, where important guidelines might be looked for, the document is either silent or irresponsibly ambiguous. For instance on multicultural science, the document says that ‘science is a universal discipline’ (p. 7). This is open to two entirely different interpretations: one, that science *can be* practised by everyone irrespective of their race, religion, class or gender; the other, that science *is in fact* practised by everyone. The former interpretation is the orthodox one, the latter is the constructivist version. On the history of science, we are told that ‘scientific understanding is developed by people whose ideas change over time’ (p. 24), but we are not told whether the ideas change because they are getting better (progressively more correct), or whether the change of ideas is merely one of fashion having no epistemic value.

The much touted document simply sends the wrong or ambiguous messages to students and to teachers: it routinely confuses science with technology, in that it equates learning science with mucking about and making things; and it puts the clarifying of ideas before the learning of concepts. Contrary to its claims, it provides little direction on crucial points for the development of school-based science programmes. Nor of course does it give any argument why each of the hundreds of New Zealand schools should develop their own programmes. The curriculum document took years, and thousands of dollars, to write. Teachers do not have these resources. It is irresponsible to throw onto them the onerous task of ‘developing with the support of their school community’ unique science programmes. Neither teachers, nor their school community, are privy to the relevant educational research, or the scientific information, required to do this. They are hard-pressed enough with teaching, and increasingly with other administrative matters. More specific and concrete assistance from the curriculum would have been welcome.

The Core Knowledge Foundation Curriculum in the U.S. is an obvious contrast to the New Zealand approach. In the 200 schools adopting the curriculum about 50 per cent of classroom time is spent teaching each student a core of knowledge that is the same material offered to every other child in the same grade throughout the school. The curriculum contrasts with skills-based curricula that are couched in terms of learning skills rather than content knowledge. In the latter, it is said that ‘first graders develop map skills’ and ‘learn about plants’. In the former, it is specified that first graders ‘identify several continents’ and ‘learn about the difference between evergreen and deciduous plants’. Constructivism – which urges teachers to build on children’s existing knowledge and to tailor instruction to the interests, values and concerns of their pupils, and which urges New Zealand schools to develop ‘unique science programmes’ – results in a myriad of different scientific competencies and incompetencies. Where there is no consistency in what children have been taught in previous grades, teachers have to fill in knowledge gaps for all pupils, thus making progress intolerably slow, or proceed at the average level and leave the others behind. It is noteworthy, but hardly surprising, that the Core Knowledge Curriculum has had excellent results in inner-city and deprived schools.[14] This is consistent with just about all studies on the educational achievement of disadvantaged pupils: the more structure, the more piecemeal the instruction, the better the achievement. Schools that adopt progressive pedagogy and minimalist curricula, compound the educational disadvantage of deprived homes.

Limitations of the Writing Team

A problem with the New Zealand science curriculum is that the writing team was narrow in its competence. It was written by people who had a good deal of teaching experience, but little advanced training in either science or education. The thirteen members of the writing group included eleven experienced school teachers and two staff from colleges of education, but there were no members of university science or education departments. The group included just one PhD in the sciences, there were no PhDs in education, there were only a few people with master’s degrees in science. Because of the absence of scientists, the group had no deep appreciation of the conceptual structure of physics, chemistry, biology, geology or astronomy; no means of authoritatively grasping the key disciplinary concepts and their interrelations. Because of the absence of educationalists (members of university education departments), the group was not in a position to appraise or utilise the immense body of pedagogical, psychological, and philosophical research on the structure-of-discipline curricula, or indeed of research on other curricular, or learning, matters. There were certainly no historians or philosophers of science on the writing group. Thus comments about history or philosophy were throw-away lines; they were, at best, at a *Readers’ Digest* level. There was no-one on the team whose professional background qualified them to seriously question the constructivist underpinnings of the LISP research and the *Draft Forms 1-5* curriculum out of which the national curriculum in science was developed.

None of this is to say that the group were not hard working and dedicated. They clearly were. But the writing group was simply not balanced. There are a range of legitimate contributors to any national curriculum: universities (who are custodians and developers of academic disciplines and who accept many of the school leaving group), businesses (who employ the pupils), teachers (who have to teach the curriculum), politicians (who represent, in some sense, the national interest), parents (whose children are intellectually formed by the curriculum), educationalists (whose business it is to know about the history and theory of curricula), and pupils (who study the curriculum). Debate rages about the authority and power each of these groups should have. In different countries, at different times, the mix differs. But the Ministry authorities in Wellington have, for whatever reasons, clearly opted for a one-sided team.

It clearly is a mistake to take too reified an approach to the curriculum, to build a curriculum out of pure consideration of the logic of subject matter, leaving aside classroom realities, children's capacities and political constraints. This happened with a number of the 1960s top-down curricula where scientists deliberated, and then handed down a curriculum for teachers to teach. An example of this was the Cambridge (U.S.) Mathematics Curriculum, where only university mathematicians were invited to contribute because it was claimed 'only the very top level of expertise is likely to be sufficient to make the necessary determinations' (Cambridge Conference on School Mathematics, 1963, p. 3).

On the other hand, it should be equally obvious that busy school teachers alone are not going to produce the most desirable curriculum. Ideally a curriculum writing team should have some mix of university science staff (who thoroughly know the subject matter and how it hangs together), university educationalists (who know the research literature on children's learning, on the history of curricula implementation in New Zealand and other countries, on forms of assessment, and so on), experienced school teachers (who know what can, and has, worked in classrooms), historians and philosophers of the discipline with an interest in education (who can provide something of the broad picture of the discipline, its development over time, and its formal and contingent relation with other subjects in the school curriculum) and ministry of education people (who know the history of local curricula, the assessment requirements, and the political constraints). The Project 2061 group of the American Association for the Advancement of Science approximates to such a ideal writing and development team (Rutherford and Ahlgren, 1990).

The New Zealand writing team did not have the right mix. To consciously exclude scientists and educationalists from the writing team was to severely limit the resulting document. The writing team did have a Policy Advisory Group that included four scientists. But this provided advice after the fact, it was not involved in the research, discussion and writing of the document. They were not intimately involved in the creation of the curriculum. Drafts of the curriculum were sent to scientists and others for comment. But again this is peripheral involvement in curriculum development. If the opinions of scientists and educationalists were thought to be worthwhile, then they should have been included in the writing team.[15]

The selection of writing team is itself a reflection of priorities and powers within the Ministry of Education. The gutting of the old Department of Education in 1989 has concentrated immense power in very few hands. Most of the work previously done by career professionals in the old Department is now farmed out on a contract basis. But the number of personnel left to draw up the tender documents and to choose the successful applicants, is correspondingly very few. How desirable has been this devolution is a separate question.

Although devolution fits in with the idea of ‘small (government) is beautiful’, one clear problem is the resulting lack of institutional memory. The more that government departments develop policy by paying consultants and conduct research by tender, then the less likely it is that the experience of the past can be reflected upon and utilised. Devolution makes it more likely that the wheel will be reinvented, and that the left hand will not know what the right hand has done, is doing, or is about to do. Devolution also means that the few key personnel and advisors left in a Ministry have inordinate powers. These few need only convert to a particular ideology for that view to then very quickly become ‘official policy’ – through the letting of policy and research contracts, and the appointment of advisory groups. This seems to have occurred in New Zealand science, mathematics and English education.

Another major problem is that the sheer body of relevant information and knowledge that should inpinge upon and inform educational deliberations is immense. Farming out curriculum contracts to busy teachers is not the best way, to put it mildly, of ensuring that this information and research is utilised. The development, implementation and assessment of the British National Curriculum is one matter that could inform deliberations about New Zealand education. But it is complex and difficult to appraise (see for instance Graham, (1993) and Flude and Hammer, (1990)). Likewise the U.S. experience with the AAAS’s Project 2061 could inform New Zealand curriculum deliberations in science, mathematics and technology. But again it is a complex and difficult subject (see Rutherford and Ahlgren, (1989) and AAAS, (1993)). There is an abundance of relevant research in educational psychology, sociology, history, and philosophy that should inform New Zealand deliberations, but again to be familiar with this requires an immense amount of time.

The advantage of having a core of well-staffed, well-qualified, well-paid, well-resourced professionals in the Ministry of Education is that they can keep abreast of research and innovation in New Zealand and elsewhere. They can develop historical and archival material. They can be a repository of educational wisdom in the buffeting winds of political change.

CHAPTER 7

A BETTER APPROACH TO SCIENCE TEACHING: THE EXAMPLES OF PENDULUM MOTION AND AIR PRESSURE

In this section the science and teaching of two topics, pendulum motion and air pressure, will be discussed in order first to illustrate the weaknesses of both constructivist theory and pedagogy, second to indicate something of the benefits of the alternative liberal or contextual approach to science education that I advocate, and third to demonstrate the fruitfulness of historical and philosophical understanding by science teachers.[1] Pendulum motion is chosen in part because it has a place in nearly all science programmes, and because it is apparently so simple. It would seem to be a case where constructivism would have a strong chance of being vindicated, as distinct from, say, quantum mechanics or genetic engineering. The science of pendulum motion also illustrates important general topics including:

- The interplay of mathematics, observation, and experiment in the development of modern science.
- The interactions of philosophy and science.
- The distinction between material objects and these objects as treated by science.
- The ambiguous role of empirical evidence in the justification or falsification of scientific claims.
- The contrast between modern scientific conceptualisations and those of common sense.

Air pressure is also chosen because it is a classroom commonplace and because it also illustrates some of the foregoing general points.

The Pendulum and the Science of Motion

In a letter of 1632, ten years before his death, Galileo surveyed his achievements in physics and recorded his debt to the pendulum for enabling him to measure the time of free fall, which, he said, ‘we shall obtain from the marvellous property of the pendulum, which is that it makes all its vibrations, large or small, in equal times’ (Drake, 1978, p. 399). To use pendulum motion as a measure of the passage of time was a momentous enough achievement, but the pendulum is also central to Galileo’s treatment of free fall, the motion of bodies through a resisting medium, the conservation of momentum, and the rate of fall of heavy and light bodies. His analysis of pendulum motion is thus central to his overthrow of Aristotelian physics and the development of the modern science of motion, a development about which the historian Herbert Butterfield has said:

> Of all the intellectual hurdles which the human mind has confronted and has overcome in the last fifteen hundred years, the one which seems to me to have been the most amazing in character and the most stupendous in the scope of its consequences is the one relating to the problem of motion.
>
> (Butterfield, 1949, p. 3)

The pendulum played a major role in the scientific revolution. Christiaan Huygens patented a pendulum clock in 1657 and used it not only for an accurate measure of time, but also to determine to a remarkable degree of precision the gravitational constant *g*, (9.82m/s^2). Newton, in his *Principia*, used this value to establish that acceleration due to gravity on the surface of the earth was the same type of acceleration as the moon's centripetal acceleration towards the earth. Newton also used the pendulum to analyse wave motion, and subsequently to ascertain the speed of sound in air. Pendulum motion figured in Newton's major metaphysical dispute with the Cartesians, namely the dispute concerning the existence of the ether (Westfall, 1980, p. 376). The importance of the pendulum in science and philosophy was equalled only by its significance for commerce, navigation and exploration. A convenient and accurate measure of the passage of time was crucial for the pressing commercial problem of determining longitude at sea,[2] as well as for everyday economic and social affairs.

Galileo and the Textbook

The standard textbook treatment of pendulum motion features the story of Galileo's discovery of the isochronic movement of the pendulum. One representative account is the following:

> When he [Galileo] was barely seventeen years old, he made a passive observation of a chandelier swinging like a pendulum in the church at Pisa where he grew up. He noticed that it swung in the gentle breeze coming through the half-opened church door. Bored with the sermon, he watched the chandelier carefully, then placed his fingertips on his wrist, and felt his pulse. He noticed an amazing thing. ... Sometimes the chandelier swings widely and sometimes it hardly swings at all ... [yet] it made the same number of swings every sixty pulse beats.
>
> (Wolf, 1981, p. 33)

This same story appears in the opening pages of the most widely used high school physics text in the world, and one widely used in New Zealand – the Physical Science Study Committee's *Physics* (PSSC 1960).

If the textbook account is to be believed, then a basic question is why it was that the supposed isochronism of the pendulum was not observed until the sixteenth century, when thousands of people of genius and with acute powers of observation had for thousands of years been pushing children on swings, and looking at swinging lamps and swinging weights, and using suspended bobs in tuning musical instruments, without seeing their isochronism. Investigators such as Nicole Oresme, Albert of Saxony, and not least of all, Leonardo da Vinci, had dealt with and drawn pendulums. In 1569 Jacques Besson published a book in Lyon detailing the use of the pendulum in regulating mechanical saws, bellows, pumps and polishing machines.[3] For centuries people had been concerned to find a reliable measure of time, both for scientific purposes and also in everyday life to determine the duration of activities and events, and the vital navigational matter of determining longitude at sea. As the isochronic pendulum was the answer to all these questions, the widespread failure to recognise something so apparently obvious is informative. It suggests that there is not just a problem of perception, but a deeper problem, a problem of epistemology, involved.

How Galileo came to recognise and prove the laws of pendulum motion is germane to teaching the topic. Teachers want students to recognise and prove the properties of pendulum motion – period being independent of mass and amplitude, and varying inversely as the square root of length. How these properties were initially discovered can throw light on current attempts to teach and learn the topic. To teach the laws of pendulum motion guided by constructivist principles is a major challenge – as always there is an evidential gap between children's experience and scientific knowledge.

Galileo's Account of Pendulum Motion

Galileo at different stages makes four claims about pendulum motion:

1. Period varies only with length; the Law of Length.
2. Period is independent of amplitude; the Law of Amplitude Independence.
3. Period is independent of weight; the Law of Weight Independence.
4. For a given length all periods are the same; the Law of Isochrony.

Contrary to many textbooks, it was not observation but mathematics, and experiment guided by mathematics, that played the major role in Galileo's discovery and proof of the properties of pendulum motion.[4] In his earliest work, in the lead up to his geometrical proof of isochronic motion, he deals with motion on inclined planes (the chords of a circle), and shows that bodies released from the top of any chord terminating at the bottom of a circle, reach the bottom simultaneously. But he adds:

> But this proof must be understood on the assumption that there is no accidental resistance (occasioned by roughness of the moving body or of the inclined plane, or by the shape of the body). We must assume that the plane is, so to speak, incorporeal or, at least, that it is very carefully smoothed and perfectly hard ... and that the moving body must be perfectly smooth ... and of the hardest material.
>
> (Galileo, 1590, p. 64)

Galileo has here introduced crucial idealising conditions. His new science is not going to be simply about how the world behaves, but rather how it should behave. Or to put it another way, his science will be about how the world would behave if various conditions were fulfilled: if the string were weightless, if the bob occasioned no air resistance, if the fulcrum were frictionless and so on. In controlled experiments some of these conditions can be fulfilled, but other conditions are incapable of being fulfilled, yet they were crucial to Galileo's science.[5]

Galileo's persistent opponent over the analysis of pendulum motion was the Aristotelian Guidobaldo del Monte, who was one of the great mathematicians of the sixteenth century, the director of the Venice arsenal and a patron of Galileo.[6] In 1602 Galileo wrote to del Monte about descent along a circular arc, the movement of the pendulum bob. In the letter Galileo outlined his theorem that 'the time of descent along any chord of a vertical circle to its lowest point remains the same, regardless of the length and slope of the plane'. He elaborated this to include the conjecture that descents along arcs of the lowest quadrant should be completed in the same time regardless of the length of the arc (Drake 1978, p.68). This was a description of the isochronic pendulum. Galileo's proof of this theorem proceeded as follows. He said:

> Let *BA* be the diameter of circle *BDA* erect to the horizontal, and from point *A* out to the circumference draw any lines *AF*, *AE*, *AD*, and *AC*. I show that equal moveables fall in equal times, whether along the vertical *BA* or through the inclined planes along lines *CA*, *DA*, *EA* and *FA*. Thus leaving at the same

moment from points *B, C, D, E*, and *F*, they arrive at the same moment at terminus A; and line FA may be as short as you please.

Figure 7.1: Galileo's Law of Chords

Theorem XXII his 1638 *Dialogue* provided what he thought was the mathematical proof of his pendulum laws, and also the counter-intuitive proposition that the quickest time of descent in free fall is not along the shortest path. He says:

> If from the lowest point of a vertical circle (*C*), a chord (*CD*) is drawn subtending an arc not greater than a quadrant, and if from the two ends of this chord two other chords be drawn to any point on the arc (*B*), the time of descent along the two latter chords (*DB*, *BC*) will be shorter than along the first, and shorter also, by the same amount, than along the lower of these two latter chords (*BC*).
>
> (Galileo, 1638/1954 p. 237)

Figure 7.2: Galileo's Mature Proof

Del Monte was not impressed by these proofs, claiming that Galileo was a better mathematician than a physicist. Reasonably enough, he could not believe that one body would move through an arc of many metres in the same time as another, suspended by the same length of chord, would move only one centimetre. Further, as a mechanic, he conducted experiments on balls rolling within iron hoops and found that Galileo's claims were indeed false: balls released from different positions in the lower quarter of the hoop reached their nadir at different times. But Galileo was not moved by these objections. In his *Dialogue Concerning the Two Chief World Systems* (1633) he says:

> Take an arc made of a very smooth and polished concave hoop bending along the curvature of the circumference *ADB*, so that a well-rounded and smooth ball can run freely in it (the rim of a sieve is well suited for this experiment). Now I say that wherever you place the ball, whether near to or far from the ultimate limit *B* ... and let it go, it will arrive at the point *B* in equal times ... a truly remarkable phenomenon.
>
> (Galileo, 1633/1953 p. 451)

Figure 7.3: Ball in Hoop

In his final great work in mechanics, *Dialogues Concerning Two New Sciences* (1638) Galileo says that:

> It must be remarked that one pendulum passes through its arcs of 180°, 160° etc. in the same time as the other swings through its 10°, 8°, degrees ... If two people start to count the vibrations, the one the large, the other the small, they will discover that after counting tens and even hundreds they will not differ by a single vibration, not even by a fraction of one.
>
> (Galileo, 1638/1954, p. 254)

Thus for any length pendulum, if we count the number of swings in 24 hours, and introduce some suitable calibration device, we have a clock. Galileo produced sketches of just such a clock.[7] And we can then vary the length of the pendulum until we have one that completes its period in exactly one second – this length became the standard metre.

Empirical Problems with Galileo's Account

These marvellous proofs of Galileo were not greeted with universal acclaim: on the contrary, learned scholars were quick to point out considerable empirical and philosophical problems with them. The empirical problems were examples where the world did not 'correspond punctually' to the events demonstrated mathematically by Galileo. In his more candid moments, Galileo acknowledged that events do not always correspond to his theory; that the material world and his so-called 'world on paper', the theoretical world, did not correspond. Immediately after mathematically establishing his famous law of parabolic motion of projectiles,[8] he remarks that:

> I grant that these conclusions proved in the abstract will be different when applied in the concrete and will be fallacious to this extent, that neither will the horizontal motion be uniform nor the natural acceleration be in the ratio assumed, nor the path of the projectile a parabola.
>
> (Galileo, 1638/1954, p. 251)

One can imagine the reaction of del Monte and other hardworking Aristotelian natural philosophers and mechanicians when presented with such a qualification. It confounded the basic Aristotelian and empiricist objective of science, namely to tell us about the world in which we live. The law of parabolic motion was supposedly true, but not of the world we experience: this was indeed as difficult to understand for del Monte as it is for present-day students, the more so if taught by constructivist-inspired teachers.

Giovanni Renieri, a gunner who attempted to apply Galileo's theory to his craft, complained in 1647 to Torricelli that his guns did not behave according to Galileo's predictions. Torricelli replied that his teacher spoke the language of geometry and was not bound by any empirical result (Segre, 1991, p. 43). Renieri, as with del Monte, is exposing one of the basic questions about the scientific revolution and modern science: how does science relate to experience on the one hand, and to mathematics on the other?. Students can be encouraged to grapple with an answer to this, although their appreciation of the great sixteenth century achievements are limited if they have not been taught geometry!

Wolf, the PSSC authors and most science textbook writers who make mention of Galileo's laws of pendulum motion suggest that any old (or young) observers who, at the time, cared to open their eyes would see the isochronic motion that Galileo supposedly saw. Not so. Del Monte, and others, did not see it. As early as 1636 the notable physicist Mersenne reproduced Galileo's experiments and not only agreed with del Monte, but doubted whether Galileo had ever conducted the experiments (Koyré, 1968, pp. 113-117). A large and influential part of the scientific community opposed Galileo's claims about isochronism. They were not just being obdurate old heads-in-the-sand, as is so often depicted in texts.

Modern researchers have duplicated the experimental conditions described by Galileo, and have found that they do not give the results that Galileo claimed (Ariotti, 1968, Naylor, 1974, 1980, 1989, Settle, 1961, 1967, 1983). Ronald Naylor for instance found that:

> Using two 76 inch pendulums, one having a brass bob, the other cork, both swinging initially through a total arc of 30°, the brass bob was seen to lead the cork by one quarter of an oscillation after only twenty-five completed swings.
>
> (Naylor, 1974, p. 33)

Del Monte and others repeatedly pointed out that actual pendulums do not behave as Galileo maintained. Galileo never tired of saying that *ideal* pendulums would obey the mathematically derived rules. Del Monte retorted that physics was to be about this world, not an imaginary mathematical world. Opposition to the mathematising of physics was a deeply held Aristotelian, and more generally empiricist, conviction.[9] The British empiricist, Hutchinson, would later say of the geometrical constructions of Newton's *Principia* that they were just 'cobwebs of circles and lines to catch flies in' (Cantor, 1991, p.219).

It is easy to appreciate the empirical reasons for opposition to Galileo's law. The overriding argument was that if the law were true, pendulums would be perpetual motion machines, which clearly they are not. An isochronic pendulum is one in which the period of the first swing is equal to that of all subsequent swings: this implies perpetual motion. We know that any pendulum when let swing, will very soon come to a halt; the period of the last swing will be by no means the same as the first. Furthermore it was plain to see that cork and lead pendulums of the same length have a slightly different frequency, and that large amplitude swings do take somewhat longer than small-amplitude swings for the same pendulum length. All of this was pointed out to Galileo, and he was reminded of Aristotle's basic methodological claim that the evidence of the senses are to be preferred over other evidence in developing an understanding of the world.

Children have the same difficulty seeing the properties of pendulum motion that the sixteenth century Aristotelians had. Even with highly refined school laboratory pendulums, they do not see isochrony of large and small amplitude swings, and their cork pendulums soon cease swinging, whilst the brass ones continue much longer. All of this experiential evidence is hard to reconcile with the 'laws' of pendulum motion. Children can either think they are stupid and need to take everything on authority, or they can conclude, as one German student did in a recent survey that 'physics is not about the world' (Schecker, 1992, p. 75). This is a case of children being in the position of the early pioneers of a science. No amount of looking will reveal isochronic motion; looking is important, but something else is required: a better understanding of science and what it is aiming to do – an epistemology of science. The Dutch historian, E.J. Dijksterhuis, had an appreciation of this when he observed:

> To this day every student of elementary physics has to struggle with the same errors and misconceptions which then [in the seventeenth century] had to be overcome ... in the teaching of this branch of knowledge in schools, history repeats itself every year.
>
> (Dijksterhuis, 1961/1986, p. 30)

Dijksterhuis goes on to make the fundamental point that has been laboured above: classical mechanics is not only not verified in experience, but its direct verification is fundamentally impossible – 'one cannot indeed introduce a material point all by itself into an infinite void and then cause a force that is constant in direction and magnitude to act on it; it is not even possible to attach any rational meaning to this formulation'.

Herbert Butterfield conveys something of the problem that Galileo and Newton had in forging their new science:

> They were discussing not real bodies as we actually observe them in the real world, but geometrical bodies moving in a world without resistance and without gravity – moving in that boundless emptiness of Euclidean space which Aristotle had regarded as unthinkable. In the long run, therefore, we have to recognise that here was a problem of a fundamental nature, and it could not be solved by close observation within the framework of the older system of ideas – it required a transposition in the mind.
>
> (Butterfield, 1949, p. 5)

This transformation from old, commonsense, Aristotelian science to modern Western science with its all together new epistemology, presents an obvious problem for constructivist teachers. Just how they manage to have this transformation make sense to students, much less get them to construct the concepts that the brightest minds struggled with for centuries, remains to be seen.

Post-Galileo Developments

It is useful to outline some of the later developments in the science of pendulum motion. They show the interaction of mathematics and experiment in scientific development, and the importance to science of the development of theoretical systems and of conceptual frameworks within which to interpret and interrogate nature. Both of these points are important for the teaching of pendulum motion.

Marin Mersenne and René Descartes corresponded at length about Galileo's pendulum theory. They established that, despite Galileo's claims, a pendulum's period was not independent of its amplitude. However it was the Dutch mathematician Christiaan Huygens who investigated these empirical claims, and refined Galileo's theory so that the empirical findings were consistent with them. Huygens' magnum opus was the *Horologium Oscillatorium* (1673, translated R. J. Blackwell, 1986). He recognised the problem identified by Descartes – 'the simple pendulum does not naturally provide an accurate and equal measure of time since its wider motions are observed to be slower than its narrower motions' (Blackwell, 1986, p. 11). Huygens changed two central features of Galileo's theoretical object, namely the claims that period varied with length, and that the circle was the tautochronous curve (the curve on which bodies falling freely under the influence of gravity reach the nadir at the same time regardless of where they were released). In contrast Huygens showed mathematically that period varied with the square root of length, and that the cycloid (the curve traced out by a point on the circumference of a wheel as it rolls) was the tautochronous curve.[11] He then devised a way (cycloid laminates at the fulcrum) of making Galileo's pendulum swing not in a circle, but in an arc of a cycloid. Once this was done the period did become independent of the amplitude and the way was cleared – once he found an effective measure for the length of a cycloid pendulum and its centre of oscillation – for the construction of reliable pendulum clocks.[12] Huygens provides the following account of his discovery of the cycloid as the tautochronous curve:

> We have discovered a line whose curvature is marvellously and quite rationally suited to give the required equality to the pendulum ... This line is the path traced out in air by a nail which is fixed to the circumference of a rotating wheel which revolves continuously. The geometers of the present age have called this line a cycloid and have carefully investigated its many other properties. Of interest to us is what we have called the power of this line to measure time, which we found not by expecting this but only by following in the footsteps of geometry.
>
> (Blackwell, 1986, p. 11)

Figure 7.4: A Cycloid Curve

Figure 7.5: Huygens' Cycloid Pendulum

Some Epistemological Lessons

At the outset of this section it was said that historical and philosophical study of Galileo's analysis of pendulum motion not only assists with pedagogical matters, but also clarifies central epistemological issues in science; the pendulum is a window onto the nature of the scientific revolution. Before turning to the pedagogical matters, a few of the central epistemological aspects will be amplified, beginning with the key distinction between real bodies and their representation within a theoretical system that works on them. This is at the heart of the differences between empiricist accounts of science and non-empiricist, objectivist, accounts. This distinction also sheds light on practical teaching matters, and on debates about constructivism and the nature of human learning.

Real versus Theoretical Objects

Galileo's theory of mechanics provides the definitions of key concepts – momentum, acceleration, average speed, instantaneous speed, weight, impetus, force, point mass and so on. These concepts were hard-won theoretical constructions, and are utilised in his account of pendulum motion. Acceleration, for instance, was initially defined by Galileo, and by all his predecessors, as rate of increase of speed with respect to distance traversed – a natural enough definition given that accelerating bodies increase speed over both time and distance, and that the passage of distance was both more measurable and more easily experienced by sight and feel. It was only in his middle age that he changed the definition to the modern one of rate of change of speed with respect to time elapsed. Without such a change of definition, the important laws of free fall would not have been discovered. A good deal of a child's school life would pass while waiting for him or her to construct this modern definition of acceleration. If the student is fortunate, and their teacher is not contaminated by constructivist dogma, then they will be told the definition, and something of its history and the choices involved.

These interlocking concepts formed the *conceptual structure* of Galileo's physics, and provided the meaning of key terms. This is Galileo's 'world on paper', as he referred to it, or his proto-theoretical system. This is the indispensable scaffolding of science that, I have maintained, children need to be provided with. But there is also a real world of material and other objects which exists apart from his, or anyone else's, theorising about it. But we can see in Galileo's practice a most important intervening layer emerging between theory and the brute world – the realm of theorised objects. These are natural objects *as conceived and described by* the relevant theoretical concepts.

Planets and falling apples have colour, texture, irregular surfaces, heat, solidity and any number of other properties and relations. But when they become the subject matter of mechanics they are merely point masses with specified accelerations; when thus conceptualised and delimited, they are no longer natural objects, but theoretical objects. In a similar way, when apples are considered by economists they become theoretical objects of a different sort – commodities with specific exchange values. When botanists consider apples they create yet other theoretical objects. For Galileo, a sphere of lead on the end of a length of rope swinging in air, when it is considered by his mechanical theory, becomes a pendulum conceived as a point mass at the end of a weightless chord suspended from a frictionless fulcrum moving in a void.

Historically, grasping the significance of this abstractive or theoretical domain between conceptual schemes and the natural world has not been easy. Pierre Duhem made a similar distinction to that being made here, but did so in terms of concrete and abstract objects. He observed that:

> It is impossible to leave outside the laboratory door the theory that we wish to test, for without theory it is impossible to regulate a single instrument or to interpret a single reading; we have seen that in the mind of the physicist there are constantly two sorts of apparatus; one is the concrete apparatus in glass and metal manipulated by him, the other is the schematic and abstract apparatus which theory substitutes for the concrete and on which the physicist does his reasoning.
>
> (Duhem, 1906/1954, p. 182)

Duhem's observation, that without theory we cannot interpret a single reading, is important for pedagogy. Instruments and measuring devices should not be dropped into a classroom without due attention to the theory that they embody and presuppose.

Concept Development

For Aristotle, a person looks at something or at a process and the mind abstracts an essence which typifies or characterises the phenomenon. The intellectual process is called abstraction. The British empiricists Hume and Locke modified Aristotle's account when they discussed the origin of ideas or concepts: first we have sensations, and then faint images of these are written in the mind. This is more a reflection theory of ideas than an Aristotelian abstraction theory. Galileo's analysis does not fit this scheme at all. As one commentator has said:

> ... the concept, say, of a 'material point with a determinate mass' does not constitute the common essence of apples, planets and projectiles. It is rather a concept of the conceptual scheme of physics which is *produced* together with the other concepts of this system and which is, precisely, *attributed* to such real objects so that their movement may be accounted for by this system as a whole.
>
> (Baltas, 1988, p. 216)

Looking at the bob of a pendulum could never, as Hume and Locke suggest, produce a faint image of a material point. Nor does watching an accelerating body produce the concept of acceleration as rate of change of velocity with respect to time elapsed. This consideration has pedagogical consequences both for the acquisition of concepts and for conceptual change, some of which are discussed in Schecker (1992) This matter is somewhat akin to Popper's recognition that:

> In science it is *observation* rather than perception which plays the decisive part. But observation is a process in which we play an intensely *active* part ... An observation is always preceded by a particular interest, a question, or a problem – in short, by something theoretical.
>
> (Popper, 1972, p.342)

The thesis of this book is that, for the most part, this theoretical structure that precedes observation, and gives meaning to instruments, is something that students need to receive from teachers; and that the quality of teaching is a function of the grasp that teachers have of the relevant theoretical systems and their ability to impart it in clear and understandable terms.

Objectivism

Galileo's analysis of pendulum motion supports non-empiricist views of scientific theory as have been developed by Althusser and Balibar (1970), Baltas (1988), Chalmers (1976), Lewin (1931), Mittelstrass (1972), Sneed (1979) and Suchting (1986). These views are all opposed to empiricist understandings of scientific theory. First, they emphasise the separation of cognitive or theoretical discourse from the real world: the world is neither created by the discourse (as in idealism), nor does it somehow create the discourse (as in various reflection theories), nor does it anchor or provide foundations for the discourse (as in empiricism and positivism). Theoretical discourse and the world are each autonomous. In this sense theory exists independently of individuals, thus it is, contrary to constructivist claims, external to individuals. Second, the views distinguish within theory between (a) the conceptual foundations of the discourse containing the definitions of theoretical and observational terms (there is no decisive distinction made between these kinds of terms); (b) the conceptual structure of the theory which is the elaboration and manipulation of the basic concepts by techniques (mathematical and logical) that produce the structure of the theory (Galileo's distant theorems and propositions) and (c) the theoretical objects of the theory which are the real or imagined objects in the world as they are conceived and described by the theory – the balance treated as a uniform line with parallel weights suspended from it, the pendulum treated as a point mass on a weightless string and so forth.

The concepts and techniques of a theoretical system enable natural events to become scientific events, and as such they can then be considered and analysed by the scientist in accord with the canons of the appropriate theory. It is as a *scientific* event that they are stripped of their everyday guises and become data or evidence in theoretical debate. The properties ascribed to these theoretical objects are derived from the conceptual foundations of the theory: instantaneous velocity, momentum, acceleration and so on. Likewise some properties cannot be ascribed because well-developed conceptual foundations exclude them; the particular theoretical discourse does not contain the concepts. Thus Galilean discourse excluded *levitas* [lightness] as a property of bodies, whereas in Aristotelianism it is one of the fundamental properties of bodies. Eclecticism is a common problem with under-developed conceptual foundations, as is the carryover of everyday and ideological concepts into the conceptual foundations of science – the use in science of everyday notions of acceleration, of species, of intentionality or of atoms.

The conceptual foundations of a theoretical discourse or research programme, to use Lakatos's terminology, are slowly built up and refined in a process of theoretical production; they generally contain elements, assumptions and aspects of pre-existing conceptual schemes, and also elements of commonsense understandings. Despite Galileo's break with so much of the Aristotelian tradition, his conceptual scheme retained Aristotelian notions of natural movement (accelerated movement without an external force) and also circular inertia. It is only very mature theoretical discourses that manage to identify all extraneous elements within them and then either redefine or jettison them. And of course the same concept often has an everyday meaning alongside its theoretical meaning, which can be a cause of confusion. As Baltas points out:

> Each concept has, as it were, two faces resembling in that respect a coin. For example 'force' is both the cause of 'acceleration' and what we exercise when we try to push some body; and 'acceleration' means simultaneously both the 'derivative of instantaneous velocity over time' and what we sense when our car speeds up.
>
> (Baltas, 1988, p. 214)

One should not strive to *replace* the commonsense concept with the scientific (a mistake of much constructivist and 'conceptual change' teaching), but rather to have children recognise when one concept is appropriate and when the other is appropriate. A child's idea of animal is something that is large and usually having four legs. The scientific idea includes ants and flies. One is not more correct than the other, it is only more, or less, correct in its appropriate domain. To say 'there is an animal in the tent', in virtue of there being a fly in the tent, is not to be scientific; it is to be mistaken about when scientific, and when everyday conceptualisations, are required.

Some Pedagogical Lessons

We know from Galileo's own hand how central his account of pendulum motion was to the establishment of his new physics, which enabled the Copernican view to eventually triumph over the entrenched Aristotelian world-view supported by common sense and endorsed by culture and the Church. Without this physics there was no effective counter to the mass of sensory evidence in favour of a stationary earth. With the new physics, Copernicus's revolutionary, heliocentric, astronomical system was able to be established. This in turn led to the development of the modern world-view which has transformed human culture and self-understanding.[13] As refined by Huygens, the pendulum became the long-sought-after accurate and reliable measure of the passage of time. Its use in accurately determining longitude at sea was vital for the great voyages of exploration and for the development of intercontinental commerce and exploitation. A convenient clock also wrought great changes in personal, social and industrial life. The clock became a common metaphor in literature, religion and philosophy; it began to affect people's world-views.[14] On historical, cultural, and practical grounds one would expect the humble pendulum and its marvellous properties to figure prominently in science education programs.

However, when the pendulum appears it is usually a mere shadow of its historical self. The PSSC physics text repeats the story of Galileo looking at the swinging chandelier during a sermon to establish its isochrony. The pendulum then disappears without trace. In the Harvard Project Physics text, the excellent and most contextual of texts, the equation,

T = 2® [SQUARE ROOT SIGN] *l/g*

is abruptly introduced for the period of the pendulum, and students are told ‘you may learn in a later physics course how to derive the formula’. The influential contemporary curriculum proposal of the U.S. National Science Teachers Association – *Scope, Sequence and Coordination* – highlights the pendulum to illustrate its claims for sequencing and coordination in science: yet nowhere in its discussion of the pendulum is history, philosophy or technology mentioned![15]

The historical experiments can be done very easily. When students are asked to record and interpret what they see, they will see some variant of what del Monte, Mersenne, and Descartes saw: pendulums that come to a halt, pendulums of different weight that lose parity in oscillation, and so on. There is an evidential gulf between this personal experience and the above formula. It is by no means clear how constructivism gets pupils over this gulf. But if one breaks away from the confines of personal experience, and sees science education as initiation into a tradition of analysis and knowledge, then pendulum motion can be the occasion for introducing some of the history of Galileo’s struggles with del Monte that has been canvassed above. Students can relive the history, and both appreciate and learn from the arguments of the key players. They can see the dependence of science upon mathematics, particularly geometry, and something of its interactions with philosophy.

What is a Misconception?

The example of pendulum motion also focuses and clarifies issues raised for science teachers by the numerous studies of children’s learning and thought processes – their alternative frameworks (Hewson, 1985), preconceptions (Osborne and Freyberg, 1985) and misconceptions (Novak, 1983). In the pendulum case did del Monte, Mersenne, Descartes have misconceptions? In one sense they did not (the pendulum behaved roughly as they said it did, not like Galileo claimed), but in another sense they clearly did have misconceptions (they did not share the conceptions of Galileo, which became scientific orthodoxy). The important thing for students is that they be introduced to the conceptual discourse of Galileo and contemporary physics. It is with respect to this discourse, or to the theoretical objects of this discourse, that they have misconceptions, it is not with respect to the behaviour of the natural world. To confuse matters by saying they do not have misconceptions because the pendulums behave as they (and del Monte) think they do, can lead to problems. It is this commonsense view of the world which science education attempts to change. The task is not easy.

To expect students to learn anything Newtonian by playing around with objects is to underestimate the epistemological revolution inaugurated by Galileo and Newton; and also to underestimate the pedagogical problems in getting children to comprehend the classical scientific world-view. Galileo’s conceptual scheme does not emerge by playing around with objects, it emerges by intellectual production using borrowed concepts, and learned logical and mathematical techniques. There is an important educational role for ‘messing about’, as Hawkings has described it, for being acquainted with the phenomena, as Mach demanded, or for tinkering around, as Feynman has suggested, but this role is not that of producing contemporary scientific concepts and understanding. Richard Dearden has aptly commented about ‘mucking around’ that:

> With very young children especially there is an important place for this kind of learning, but such limited and undirected curiosity does not amount to science. All of this could and did and does go on where science had never been heard of. Such finding out does not even begin to resemble science until problems start to present themselves which cannot be solved without putting forward, and then testing experimentally, suggested solutions of a non-obvious kind.
>
> (Dearden, 1967, p. 143)

It is notorious how poorly science students and teachers understand pendulum motion. Most teachers, and some students, can repeat the four laws of pendulum motion, but their conceptualisation of the movement is weak. Frederick Reif has conducted revealing studies on this conceptualisation. Students and teachers were given Figure 7.6 for the pendulum’s movement and asked to write in the acceleration of the bob at each of the points *A*, *B*, *C*. Eighty per cent of physics students get the answer wrong. The correct answer to the question is given in Figure 7.7.

Figure 7.6 Moving Pendulum

Figure 7.7 Acceleration of Bob

One can appreciate the intellectual problems involved in getting the correct answer. At the bob’s lowest point, when its tangential speed is greatest, its acceleration is vertically upwards. When the bob is at its top and apparently stationary, it is nevertheless accelerating along the radius of its arc. The first diagram represents the real pendulum, the second diagram represents the pendulum as described by the theory of classical mechanics, the theorised pendulum. Being able to represent the second correctly depends upon a very sophisticated grasp of the relevant theoretical system. Such a system is not something generated by looking at, or observing, the first object: it comes about only by good teaching by informed teachers. As Dearden observed:

> Far from being like trotting around a garden, learning science and what is characteristic of scientific inquiry involves initiation into a social tradition of inquiry and is therefore something which, one way or another, has to be taught.
>
> (Dearden, 1967, p. 143)

The classroom problems encountered when the theoretical object of science is discordant with everyday experience of material objects is nicely illustrated in the following classroom exchange between a teacher, who has previously introduced the concept of acceleration, and three students who are clearly struggling to apply the concept to the motion of a body thrown upwards, the pendulum situation.

Teacher: Suppose I toss a ball straight up into the air like this (*demonstrates*). What is the ball's acceleration at the top of the trajectory?

Student 1: Zero.

Student 2: Yeah, zero.

Teacher: Why is it zero?

Student 1: Well, at the top the ball stops moving, so it must be zero.

Teacher: OK. If I place the ball on the table so that it does not move, is it accelerating?

Student 2: No. It is not moving.

Teacher: What if I roll the ball across the table so that it moves at a constant velocity (*demonstrates*). Is the ball accelerating in this case?

Students 1 and *2*: Yeah.

Student 3: No way! If the ball is rolling at a constant speed it does not have any acceleration because its speed does not change.

Teacher: So it appears that an object can have a zero acceleration if it is standing still or if it is moving at a constant velocity. Let's reconsider the case where the ball is at the top of its trajectory (*demonstrates again*). What is the ball's acceleration when it is at the top?

Student 3: It would be zero because the ball is standing still at the top. It's not moving – it has to turn around.

Student 2: I think it might be accelerating because it gets going faster and faster.

Student 1: Yeah, but that doesn't happen until it gets going again. When it is standing still it is not accelerating.

(Mestre, 1991, p. 58)

Conceptual Precision, Mathematics and Science Learning

The Waikato group's contribution to the 1992 Monash seminar decries traditional science teaching, in part because:

> Teaching based on this traditional view of science attempts to transmit to learners concepts which are *precise* and *unambiguous*, using language capable of *transferring* ideas from expert to novice (teacher to student) with *precision*.
>
> (Carr, *et al*., 1994, p. 147)

This is a peculiar complaint. One would have thought that this is exactly what teachers should be doing. In the simple case of the pendulum, one can see how it is only by recourse to *precise* definitions that students will be able to understand the scientific picture. Without these, the very idea of a stationary object accelerating is beyond their grasp, as is the idea of a body moving horizontally yet accelerating vertically upwards. This is not to say that sophisticated definitions have to be given to children at the outset, but this must remain the *telos* of science instruction.

The Canadian Jesuit priest and philosopher, Bernard Lonergan, in an address on ‘The Teaching of Physics’, expressed this point.

> Teaching physics without students knowing the relevant mathematics is not teaching physics. What does a scientist meant by acceleration? He means ds^2/dt^2. If you know what is meant by those symbols from the differential calculus, you know exactly what is meant by acceleration and velocity. ... It is possible to give students who have not done the mathematics some approximate notion of it, but it will take them a great deal of time to understand that approximate notion, and when they get it, they will be able to do very little with it, because it is not accurate, and its implications do not stand out.
>
> (Lonergan, 1993, p. 145)

He went on to state a view diametrically opposed to the Waikato opinion above:

> ... the teaching of physics without a proper account of the fundamental notions ... gives an illusion of knowledge, a false idea of what science is. And it clutters the mind.
>
> (Lonergan, 1993, p. 145)

It should be obvious in the classroom excerpt above, that no amount of everyday talking, clarifying, or investigating is going to result in the children seeing that a stationary body is accelerating. Nor is any amount of Kelly-like testing of ideas against reality going to result in the scientific concept. It is only when this discussion and testing is informed and guided by the correct, and exact, scientific concepts that the relevant relations will be revealed. It is the teacher’s job to provide these conceptual tools for fruitful discussion and testing. Bernard Lonergan is correct on this point, and he and others of his opinion, are in direct opposition to the ideals of Waikato science education.

Clearly Lonergan sets a standard for science education that not all children can reach, and that is inappropriate for certain ages, but the point is that it is the standard towards which children and teachers ought be aiming. He is right to say that without the differential calculus there can be an approximate idea of acceleration, but it is only approximate. Neither children or teachers should be lulled into thinking they have adequately learned or taught the topic without reference to the calculus. It is this lack of standards, or goals, that weaken the New Zealand science curriculum and results in having children’s minds ‘cluttered’.

Science and culture

If pendulum motion is taught in the contextual or liberal manner that has been advocated, then this commonplace curriculum topic can illustrate something of the complex interaction of science with culture, philosophy and commerce. This is something that can remain with students long after they have forgotten the formulae for the period of a pendulum.

To modern readers, it seems odd that Galileo would go to so much trouble to provide mathematical proofs, or demonstrations, of his claimed properties of the pendulum. This becomes a little clearer when it is seen that mathematics (Euclidean geometry) was regarded then as a body of certain knowledge. Galileo remarked at one point that our knowledge of geometrical theorems is the equal of God's knowledge of those theorems. For Galileo, and his contemporaries, nothing less than certainty was the goal of science.[16] Thus with Galileo we have the case where an overall epistemology affected the conduct of his science.

But, further, his epistemology was in turn influenced by his religion. Galileo's physics was put forward in the service of the Copernican world view. It was known that Copernicus's helio-centric theory of the solar system was in conflict with the standard readings of Scripture and with traditional Church teaching. Following the Augustinian tradition of hermeneutics, it was widely held, certainly by the Inquisition and by Galileo, that Scripture had to be taken at its face value except in situations where demonstrable and certain secular knowledge conflicted with it.[17] In the case of, and only in the case of, such conflict could Scripture be reinterpreted in a metaphorical or poetic manner. For the Catholic Church this became a particular concern during the Counter Reformation. Thus to establish Copernicianism, and to ward off the attentions of the Inquisition, Galileo needed certainty in his physics. Geometry gave him this. These are all complex matters, and the best one might hope for is to have good students appreciate the questions, rather than believe they have answers.

And there is a veritable abundance of interesting questions that can be explored about the pendulum, timekeeping, and Western exploration and domination. Beginning with trying to have kids understand how accurate timekeeping was crucial for solving the long-standing problem of ascertaining longitude at sea (or on land).

Teaching about Air Pressure: The Contrast between Contextural and Professional Approaches

I advocate a contextual or historical approach to the teaching of science, an approach that teaches *about* science at the same time that children learn the content of science. This approach contrasts with on the one hand professional approaches, where context is ignored, and with constructivist approaches where only the immediate context of science is considered, and content is always under a cloud. The best way to appreciate the contrasts between contextural and professional approaches to teaching science is to look at the different ways that specific topics are taught. Air pressure, a central topic in most elementary and high school science courses, will serve here as an example.

Historical Approaches

There have been good historical treatments of air pressure in science programmes. Air pressure and Boyle's vacuum pump were the subject of the first of Conant's 1957 Harvard Case Studies. One of three physics units in the nine Klopfer Case Studies (Klopfer, 1969a) is on air pressure (Case 6). This unit is comprised of a collection of texts, extracts, activities, slides, hardware and experiments. The case study:

> ... combines the story of the overthrow in the seventeenth century of the ancient Aristotelian doctrine that nature abhors a vacuum with the application of hydrostatic principles to explain the phenomena associated with atmospheric pressure. The pioneer work of Torricelli with the barometer included the idea that the mercury column standing at a height of about 30 inches above the level of mercury in a dish was balanced by the weight of the 'sea of air' pressing on the surface of the mercury.

(Klopfer and Cooley, 1961, p. 10)

Case 6 contains material on Galileo’s incorrect account of why the lift pump can only bring water up thirty four feet – his idea was that if any longer than this, the column would break under its own weight. The case asks students to hold up a length of chewed gum and see what its critical (nonbreaking) length is; and asks them whether by analogy it is possible that a similar situation will occur in a long column of water. The case also has material on Pascal’s Law, and recommends the building of a simple hydraulic press to illustrate the principles. Among other benefits, the case allows students to see that great scientists such as Galileo get things wrong, and persist in erroneous beliefs. This is even more apparent in Galileo’s commitment to a completely false account of the tides, a subject with which he occupied the final day of his 1633 *Dialogue*, and which he believed provided the best argument for the Copernican world view. History shows the fallibility of science and scientists, as well as their triumphs.

Each of Klopfer’s Case Studies has objectives listed under three headings:

1. Information about science subject matter and the narrative of the case.
2. Understanding of science concepts and principles.
3. Understanding of ideas concerning science and scientists.

The objectives that it lists under 3 for the unit on air pressure are instructive. It is said that after studying the unit, students should understand the following ideas concerning science and scientists:

- The meanings and functions of scientific hypotheses, principles and theories, and their interconnections.
- The difference between science and applied science or technology.
- The dynamic interaction between ideas and experiments, between thinking and doing, in scientific work.
- That a chain of reasoning, which often involves many assumptions, connects a theory with hypotheses that can actually be tested by experiments and observations.
- That factors involved in the establishment of a scientific theory or concept include experimental evidence, the personal convictions of participating scientists and the theory’s usefulness.
- That scientific explanations of natural phenomena are given in terms of accepted laws and principles.
- That scientists are individuals possessing a wide range of personal characteristics and abilities.
- That science is an international activity.
- The nature and functions of scientific societies.
- That progress in science is, in part, dependent upon the existing state of technology and on other factors outside of science itself.
- That free communication among scientists through journals, books, meetings and personal correspondence is essential to the development of science.
- That new observations have a trigger effect: they shake up established concepts and lead to new hypotheses and new experiments.

- That new apparatus and new techniques are important in making possible new experiments and the exploration of new ideas.

This list could double as a suitable statement of the objectives of any course in the history and philosophy of science, as well as any programme of study in science.

Klopfer's materials aimed at providing an education about science as well as an education in science, and with what are often called 'intangible' outcomes. Of 47 teachers participating in one review of the History of Science Case materials, 64 per cent said that their students gained intangible benefits that were not measured by tests. Some teachers' commented as follows:

- The students obtained a new feeling for the meaning of science.
- Discussion and opinions of class members played a larger part than normal ... critical evaluation of science and scientists in our society was encouraged.
- Students gained a feeling of being part of a great adventure

(Klopfer and Cooley, 1961, p. 128).

Air pressure is a ready-made field for integrating history of science into science teaching. There is a natural progression and parallelism between the evolving ideas and investigations of students and the historical story. Thirty years after the Klopfer Case Study, Joan Solomon in the U.K. also wishing to incorporate historical and social themes into school science, wrote a booklet on the same subject titled *The Big Squeeze* for the British Association for Science Education (Solomon, 1989). It promotes understanding of air pressure by traversing the ancient Egyptians and Greeks, medieval pumps and bagpipes, Galileo's ideas, his student Torricelli's famous experiment with a tube of water to create a vacuum and the diverse interpretations advanced to account for the 'space' above the water column, Torricelli's mercury barometer, Pascal's experiment of taking a barometer up a mountain and recording the changes in height of mercury supported and thus suggesting that air pressure is the result of the weight of air above the mercury, von Guericke's Magdeburg hemispheres, and finally, Boyle's vacuum pump and his speculations about the 'springiness of air'.

With good teaching, students can easily be led through this sequence of concepts and experiments.[18] First, students can conjecture about whether there is anything in air or whether it is essentially empty. After thinking about tests of their conjectures they can be shown that air is difficult to compress – an empty test tube pushed into water shows this. If the same test tube is filled with water and then raised out of the beaker we see the barometer situation. Second, students can be asked whether there would be a limit to the length of the water column supported in the test tube, and why the column is supported. Holding a clear plastic garden hose clamped at one end and placing the other end in a bucket of water and then suspending it from a building provides an answer to this question. Third, students can conjecture whether a heavier liquid would have a less high column supported, and what the predicted height of a mercury column would be. Finally, the creation of a vacuum in a cylinder and the subsequent pulling of a piston into it can be shown, and thus the basis of Newcomen's steam engine demonstrated.

With judicious use of assignments, experiments and essays a great many of the objectives of the HOSC unit on air pressure and the more general objectives of a contextual science programme, can be met –

provided, as always, that the teacher knows the subject matter and its history. The interplay of science with philosophy on the one hand, and with technology on the other, can be beautifully seen: the Aristotelian doctrine of ‘nature abhors a vacuum’ can be appreciated; the influence of this on scientists as prominent as Galileo can be seen; the efforts to support this philosophical and scientific doctrine in the light of Pascal’s and Torricelli’s demonstrations of its seeming falsity can be outlined; and by students making their own primitive steam engines (versions of Newcomen’s cooling-induced vacuum engine), or just pistons and cylinders, the technical difficulties in the advancement of the science of air pressure can be appreciated. Such teaching results in, among other things, children having a sense of participation in a tradition of thought and analysis: a not minor gain.

A Professional Approach

A standard professional approach to the topic of air pressure can be found in the PSSC *Physics* text (1960), which was the first National Science Foundation-funded high school science programme, and has been used by millions of students throughout the world. It contrasts markedly with the above historical treatment found in the Harvard Case Studies, the HOSC, Project Physics, and British materials. It is noteworthy that in the thirty-four chapters of the text not one is devoted to air pressure, nor is it mentioned in the index of approximately one thousand entries. Without mentioning air pressure, its treatment begins with Boyle’s Law and a model of colliding molecules in a chamber. The discussion of this law assumes the existence of air pressure; however, all developments up to Boyle are ignored. There is no mention of Torricelli nor of Pascal, much less are Aristotle and the *horror vacui* doctrine mentioned. Boyle’s Law is explained using the mole concept and it is stated as:

> At a given temperature the pressure exerted by a gas is proportional to the number of molecules divided by the volume they occupy. $P = K x N/V$, where K is the proportionality factor.
>
> (PSSC, 1960, p. 159)

Notably absent from the PSSC discussion is any mention of technology. Although the expected change in the *P-V* relation is discussed for rarefied atmospheres, there is no mention of a barometer in the chapter; barometers are relegated to end-of-chapter exercises. Students can study the gas laws in the PSSC physics programme without their connections to barometers and weather changes being mentioned or explained. Similarly water pumps, steam engines and all other technological uses of air pressure are omitted. The momentous connection of science with technology, and its dramatic effect on the transformation of economic and social life, is entirely omitted from PSSC physics. Not just PSSC but many of the other reform projects of the early 1960s removed applied aspects of science from their programmes. One reviewer of the 1960s reforms has said:

> The first major changes in all the NSF supported curriculum reform of the ‘60s was removing all technology and presenting pure science ‘in a way it is known to the scientist’. It is only recently that many are proclaiming the fallacy of such efforts.
>
> (Yager and Penick, 1987, p. 53)

Clearly pendulum motion and air pressure can be taught in a more engaging and informative manner than is currently done. However, such contextual teaching can only occur if teachers know something about the context of science, if they know some history and philosophy of science. So long as New Zealand science teacher education programmes exclude history and philosophy of science, so long as they (and teacher development courses) remain preoccupied with children's learning and children's science, then the possibility of engaging and mind-expanding science teaching is diminished. This is a loss to both New Zealand education and society.

In contrast I agree with the American Association for the Advancement of Science when they say that:

> Science courses should place science in its historical perspective. Liberally educated students – the science major and the non-major alike – should complete their science courses with an appreciation of science as part of an intellectual, social, and cultural tradition. ... Science courses must convey these aspects of science by stressing its ethical, social, economic, and political dimensions.
>
> (AAAS, 1989, p. 24)

CHAPTER 8

A BETTER APPROACH TO TEACHER EDUCATION: THE INCLUSION OF HISTORY AND PHILOSOPHY OF SCIENCE

The contextual teaching of science does not, of course, provide all the answers to the present science education crisis – ultimately these answers lie deep in the heart of culture and economics. However the history and philosophy of science has some contribution to make to the overall task of improving science teaching and learning, and developing a more scientifically literate and appreciative society.[1]

Teacher Education

Everyone agrees that intelligent, knowledgeable and engaging teachers, who are interested in children, and know how to manage classrooms and teach creatively, are crucial for good education. As well, teachers increasingly have to do more than just teach. Both New Zealand and Australia have followed the U.S. model of devolving financial, administrative and curricula matters to local schools. Consequently teachers have to tailor national curricula for local use, take part in school governance, develop policy on a range of discipline and welfare matters, assist with resource allocation and curriculum priorities in the school and so on. Well prepared teachers are necessary for these complex and important tasks. There has, however, been less agreement on how best to prepare such teachers (Yager and Penick, 1990). This question has been long debated, with contributions from entrenched professional and academic interests, and with political and economic expediency looming over most policy decisions. There is, of course, a prior question about how to recruit science teachers. Economics, cultural values, industrial matters and other extra educational factors affect a person's desire to become a teacher. Recruitment is a pressing problem. In Australia, teacher education programmes routinely have the lowest entry mark of all university programmes.[2] In the U.S. the American Physical Society warned that: 'The young person, fresh out of college or graduate school, who wants to teach physics in high school or middle school may soon be extinct' (APS, 1986, p. 1033).[3]

In 1986 two reports on teacher education were published in the U.S. that galvanised debate on the subject – the Carnegie Foundation's *A Nation Prepared*, and the Holmes Group's *Tomorrow's Teachers* (see Fraser, 1992). There are a range of views about the best organisation of teacher training programmes. Some advocate no training at all: just take interested science graduates and put them in front of classes. This was the old British private school method of training. In the U.K. the government has moved to partially resurrect this system with its proposal to bypass university teacher training in favour of an in-school apprenticeship.

Where education studies are required for prospective teachers, their content has been contentious. Such studies usually consist of both theoretical or foundation studies (typically philosophy, sociology and psychology of education)[4] and applied or pedagogic studies (typically curriculum, teaching methods, and practice teaching). Increasingly teacher training stresses the 'practical' side of training, with more and more emphasis being placed on in-school work with experienced teachers. Notoriously, foundation studies are regarded by trainee teachers as the least relevant part of their programne. I will suggest here ways in which history and philosophy of science programmes can substitute for, or enrich, the usual foundation offerings, and greatly diminish the ‘irrelevance’ factor. Further HPS can enrich the standard methods or curriculum and instruction courses.

Constructivists and non-constructivists agree that an appreciation of the nature of science is important for the professional life of a teacher. But in New Zealand this understanding is simply not developed in teacher training programmes, and appears only rarely in in-service programmes.

The Contribution of History and Philosophy to Science Teaching

The putative contribution of history and philosophy of science to science education can be itemised as follows:

- HPS can humanise the sciences and connect them to personal, ethical, cultural, and political concerns. There is evidence that this makes science and engineering programmes more attractive to many students who currently reject them.
- HPS, particularly basic logical and analytic exercises – does this conclusion follow from the premises? and, what do you mean by such and such? – can make classrooms more challenging, and enhance reasoning and critical thinking skills.
- HPS can contribute to the fuller understanding of scientific subject matter – it can help to overcome the ‘sea of meaninglessness’, as Joseph Novak once said, where formulae and equations are recited without knowledge of what they mean or to what they refer.
- HPS can improve teacher education by assisting teachers to develop a richer and more authentic understanding of science and its place in the intellectual and social scheme of things. This has a flow-on effect, as there is much evidence that teachers’ epistemology, or views about the nature of science, affect how they teach and the message they convey to students.
- HPS can assist teachers appreciate the learning difficulties of students, because it alerts them to the historic difficulties of scientific development and conceptual change. Galileo was forty years of age before he formulated the modern conception of acceleration, despite prolonged thought he never worked out a correct theory for the tides. By historical studies teachers can see what some of the intellectual and conceptual difficulties were in the early periods of scientific disciplines. This knowledge can assist with the organisation of the curriculum and the teaching of lessons.
- HPS can contribute to the clearer appraisal of many contemporary educational debates that engage science teachers and curriculum planners. Many of these debates – about constructivist teaching methods, multicultural science education, feminist science, environmental science, inquiry learning, science-technology-society curricula and so forth – make claims and assumptions about the history and epistemology of science, or the nature of human knowledge and its production and validation. Without some grounding in HPS, teachers can be too easily carried along by fashionable ideas which later, sadly, ‘seemed good at the time’.

An Argument for HPS in Science Teacher Education

Twenty-five years ago Israel Scheffler argued a case for the inclusion of philosophy of science in the preparation of science teachers.[5] It was part of his wider argument for the inclusion of courses in the philosophy of the discipline in programmes that are preparing people to teach that discipline. His suggestion was that: 'philosophies-of constitute a desirable additional input in teacher preparation beyond subject-matter competence, practice in teaching, and educational methodology' (Scheffler, 1973, p. 40). He summarised his argument as follows:

> I have outlined four main efforts through which philosophies-of might contribute to education: (1) the analytic description of forms of thought represented by teaching subjects; (2) the evaluation and criticism of such forms of thought; (3) the analysis of specific materials so as to systematise and exhibit them as exemplifications of forms of thought; and (4) the interpretation of particular exemplifications in terms accessible to the novice.
>
> (Scheffler, 1973, p. 40)

For the most part Scheffler's suggestion, at least as far as science education is concerned, went unheeded: a fact witnessed to by the title of a 1985 paper 'Science Education and Philosophy of Science: Twenty-Five Years of Mutually Exclusive Development' (Duschl, 1985). Duschl's paper itemised the missed opportunities and shortsighted curricular projects that resulted from the development of science education largely separate from the disciplines of history and philosophy of science. Pleasingly, in recent times there has been some rapprochement between these fields (Matthews 1990c, 1994).

This section will restate parts of Scheffler's argument, it will develop some additional considerations pertaining to it, and it will set the discussion in the context of contemporary debate about science, science education and teacher training. With changed time and circumstances, Scheffler's arguments might find more adherents than when they were initially proposed. My revision of Scheffler's argument has two planks: first pedagogical, second professional.

Concerning pedagogy, or classroom teaching, my argument is that, other things being equal, science teachers with HPS interests and competence will make science more interesting and understandable; a human face can be put on science, and routine topics in the science classroom can be the occasion for the development of critical and logical thinking. Professionally, my argument is that educators need to have some appreciation of the body of knowledge and the methods of investigation into which they are inducting students. Educators, as distinct perhaps from mere conveyors of information, need to have some global understanding of the discipline they are teaching, some understanding of its part in the overall intellectual scheme of things. This appreciation can only be acquired by HPS studies. Further, as professionals, science teachers are constantly engaged with questions that assume certain positions in HPS, questions such as constructivism, multicultural science education, ethics and science, feminism and science, religion and science, and a host of others. These questions can only be answered by turning to considerations in the history and philosophy of science.

Many others apart from Israel Scheffler have argued that HPS should be part of the education of science teachers – the British *Thompson Report* in 1918 said 'some knowledge of the history and philosophy of science should form part of the intellectual equipment of every science teacher in a secondary school' (BAAS, 1918, p. 3). The Science Council of Canada, after advocating increased attention to HPS matters in the science curriculum, said: 'Although Council does not expect children or adolescents to be trained in the philosophy of science, it does expect science educators to be trained in this area' (SCC, 1984, p. 37). A 1981 review of the place of philosophy of science in British science-teacher education said:

> This more philosophical background which is being advocated for teachers would, it is believed, enable them to handle their science teaching in a more informed and versatile manner and to be in a more effective position to help their pupils build up the coherent picture of science – appropriate to age and ability – which is so often lacking.
>
> (Manuel, 1981, p. 771)

Michael Polanyi suggested that HPS should be as much a part of science teacher education as literary and musical criticism is part of literary and musical education. So also it should be odd to think of a science teacher who has no knowledge of the terms of their discipline – 'cause', 'law', 'explanation', 'model', 'theory', 'fact'; no knowledge of the often conflicting objectives of their own discipline – to describe, to control, to understand; or no knowledge of the cultural and historical dimensions of their own discipline – the momentous issues involved in Galileo's trial, the cultural impact of Darwin's theory, the transformation in the quality of life brought about by Pasteur's and Jenner's discoveries, the challenges of genetic engineering and so on. Others have also indicated the advantages of including HPS in science teacher education programmes (Eger, 1987, Robinson, 1969, Summers, 1982).

One contribution of HPS is to connect topics in particular scientific disciplines, to connect the disciplines of science with each other, to connect the sciences generally with mathematics, philosophy, literature, psychology, history, technology, commerce and theology. And finally, to display the interconnections of science and culture – the arts, ethics, religion, politics – more broadly. Science has developed in conjunction with other disciplines, there has been mutual interdependence. It has also developed, and is practiced, within a broader cultural and social milieu. These interconnections and interdependencies can be appropriately explored in science programs from elementary school through to graduate study. The result is far more satisfying for students than the unconnected topics that constitute most programmes of school and university science. Courses in the sciences are too often, as one student remarked, 'forced marches through unknown country without time to look sideways'. Many examples have been given where HPS can contribute to better, more coherent, stimulating and critical teaching of specific curriculum topics, where HPS can increase participation rates and so on.[6]

These examples from the educational 'bottom line' are compelling, but they are not the only ones that can be advanced. Teachers, as professionals, should have historical and philosophical knowledge of their subject matter quite independently of whether this knowledge is directly used in classrooms: teachers ought to know more about their subject than what they are required to teach. Teachers have a professional responsibility to see beyond the school fence. They are dealing with the formation of children's minds, and introducing children into what John Dewey called the intellectual conversation of mankind. Science teachers, in particular, are introducing children to a tradition that is complex, rich, influential and of great cultural significance. In contrast to drill sergeants or political commissars teachers should have some perspective on their tradition. They have a responsibility to society, to their profession, and to their students both to understand science and to see science in its broad historical, philosophical and cultural contexts.

But despite the admonitions to bring HPS and science education into closer contact, not much, until recently, has been done about it. Some years ago, Robert Ennis opened a comprehensive review of the literature on philosophy of science and science teaching with the melancholy observation that: 'With some exceptions philosophers of science have not shown much explicit interest in the problems of science education' (Ennis, 1979, p. 138).

Ennis listed six questions that science teachers constantly encounter in their classrooms and staffrooms, questions that the deliberations and researches of philosophers of science could illuminate. These questions were: What characterises the scientific method? What constitutes critical thinking about empirical statements? What is the structure of scientific disciplines? What is a scientific explanation? What role do value judgements play in the work of scientists? and, What constitute good tests of scientific understanding? These questions are of perennial concern to science teachers, and science teacher-education programmes should initiate the exploration of them. But more contemporary questions can be identified to which philosophers can contribute – feminism and science, multiculturalism and science, constructivist theory, environmental ethics and so on. My argument is that these are not extracurricular or add-on questions for science teachers: philosophy of science is part of the fabric of science teaching. The issue is just how clearly this is recognised and how well teachers are prepared for dealing with the inevitable philosophical questions they confront in classrooms and staffrooms.

Teachers' Epistemology

It is not just the subject matter of science that raises philosophical questions for teachers and students. The choice of texts, the conduct of classes, and the assessment of students, also raise these questions. The teacher needs to have an idea of what science is, needs to have a sense of the 'essence' of science, an image of science that is going to be conveyed to classes and which is going to inform decision-making about texts, curriculum, lesson preparation, assessment and other pedagogic matters. Joseph Novak remarked that 'any attempt to teach the content of science that does not consider its complex 'conceptual web,' and its evolving nature, is destined to failure, provided that our objective is *meaningful*, rather than verbatim, rote learning' (in Good and Wandersee, 1992). Israel Scheffler dwelt on this point in his 1973 article where he contrasted the capacities required for *doing* science (being a scientist) with the capacities required for *teaching* science (being a teacher). He said that:

> The teacher of science ... needs to have a conception of the field of science as a whole, of its aims, methods, and standards; he needs to have principles for selecting materials and experiences suitable for inducting novices into the field, and he needs to be able to communicate both with novices and with scientific sophisticates ... But the scope of this requirement is, I suggest, virtually indistinguishable from that of the philosophy of science.
>
> (Scheffler, 1973, pp. 35, 36)

This understanding of science is an important part of the background knowledge that teachers bring to their work; it structures the 'pedagogical content knowledge' that Shulman has identified as so important for teaching. Beyond the specific concepts, the meaning of which is better grasped by philosophical elucidation, are broader questions of: what is this thing called Science? What typifies scientific method? Has the 'nature' of science remained the same over the centuries? Does its epistemology change? What are its characteristic tests for truth claims? How do these differ from other intellectual pursuits? What is the relevant role of observation and reason in the conduct of science? Do and should ethics and politics enter into science? What is the role of authority in science? Are there any typically scientific attitudes that characterise good scientists and that might be encouraged in pupils? A teacher's epistemology or theory of science influences the understanding of science that students retain after they have forgotten the details of what has been learned in their science classes.

Answers to these foregoing questions constitute a teacher's view of the 'nature of science' which is conveyed to students in class. After four or more years in a science classroom, students come away with some teacher-influenced image of science: this ought to be as sophisticated and realistic as is possible in the circumstances. A teacher's theory about the nature of science, his or her epistemology, can be conveyed explicitly or implicitly. This epistemology affects the classroom behaviour of teachers: how it is formed, and what effects it has on teacher practice have been the subject of many recent studies.[7]

One thing that is known is that a teacher's epistemology is picked up indirectly. In 1989 only four of fifty-five institutions providing science teacher training in Australia offered courses in HPS. In 1990, of the fifteen leading centres of science teacher training in the U.S. only half required a course in philosophy of science; the proportion in the remaining hundreds of centres is likely to be far lower (Loving, 1991). The situation in the U.K. is no more encouraging. Susanne Lakin and Jerry Wellington in their study of U.K. science teachers' understanding of the nature of science, observed that:

> Teachers lack of knowledge about the nature and history of science emerged strongly in the study ... As well as verbally recognising that their knowledge was patchy and their ideas not well formulated, non-verbal signals reflected an insecurity when the issues were probed in depth.
>
> (Lakin and Wellington, 1994, p.186)

and noted that: 'The lack of reflection was most apparent in the neglect of the cultural, moral and philosophical aspects of science'. A circumstance unlikely to be improved until HPS studies become accepted as a routine part of science teacher education, and until the gulf between the science education community and the history and philosophy of science communities is bridged. HPS staff should contribute to the labours of their science education colleagues in the preparation of Klopfer-like Case Studies, and the more general exchange of information.

A teacher's epistemology is thus largely picked up during his or her own science education; it is seldom consciously examined or refined. If university science departments taught science better, that is gave their graduates a better feel for science, a richer understanding of its methods and its place in history and culture, a more competent and informed grasp of its epistemology, then the task of teacher education programmes would be lessened. Meanwhile, under the influence of child-centered constructivism, more and more time is taken up learning about children's science.

The art of the teacher is to judge the sophistication of his or her students, and present a picture of science that is intelligible to them without being overwhelming. Students need to get their feet, to become familiar with a tradition, before they are confronted with the 'cutting edge' questions. The teacher may have strong opinions on various HPS issues, but the point of education is to develop the students' minds, which means giving students the knowledge and wherewithal to develop informed opinions. If HPS in science teaching becomes a catechism, then it defeats one of its major purposes. HPS in teacher training programmes can do something towards broadening the vision of teachers, and having their students not only arrive at destinations (scientific competence), but arrive with broader horizons, having travelled with a different view. In the long run this contributes to the health of science.

History of Science and the Psychology of Learning

Thus far, the argument for HPS in teacher education has been made in terms of HPS's contribution to the teaching of specific subject matter, its integrative function in bringing science and other disciplines – history, mathematics, technology, literature – together, and its importance for a professional's understanding of his or her occupation. However increasingly, HPS is being shown to be also relevant to problems in the learning of the sciences.

Joseph Nussbaum (1983) provided an early review of the relevant science education literature dealing with individual learning and the history of science. Subsequent contributors to this area of research have included Gauld (1991), Nersessian (1989), Niedderer (1992) and Wandersee (1985). A model paper in this research tradition is that of Melvin Steinberg *et al.* (1990) on how the study of Newton's slow conceptual development out of impetus theory towards the inertial mechanics of his 1687 *Principia* can illuminate the conceptual journey that modern students have to make from their naive non-inertial misconceptions to an understanding of the mechanics of the mature Newton.

More generally, important studies of individual conceptual change in science, that is, science learning, have made use of historical and philosophical theses. Peter Hewson's (1981) initial formulation of the conceptual change model of science learning quotes Kuhn and Lakatos on the conditions for theory change and, following the latter, reports that 'some of the most important conceptions influencing conceptual change in an individual were found to be ... the metaphysical [and epistemological] commitments which he or she held' (Hewson, 1981, p. 391). The influential Posner *et al.* (1982) study, to which Hewson contributed – 'Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change' – also draws upon the accounts of scientific theory change given by Kuhn, Toulmin and Lakatos.

Susan Carey, a psychologist, has suggested that success in comprehending the complexity of conceptual change in science students will 'require the collaboration of cognitive scientists and science educators, who together must be aware of the understanding of science provided by both historians and philosophers of science' (Carey, 1986, p. 1125). Richard Duschl, Richard Hamiliton and Richard Grandy – a science educator, a cognitive psychologist and a philosopher of science – have taken up Carey's suggestion and have, relying on cognitive studies of science, provided an extensive review of the ways in which the process of theory development by scientists can be compared to an individual's acquisition of knowledge of the world (Duschl, *et al*., 1992).

It has been indicated that major research programmes in science learning are based on assumptions about the history and philosophy of science. Therefore preservice or inservice courses for science teachers in the psychology of learning ought to include or be augmented with studies of the history and philosophy of science. Without such courses, students and teachers must take on faith the views attributed to philosophers such as Kuhn, Toulmin and Lakatos. This is less than satisfactory preparation for a profession committed to rational inquiry.

What Type of Course?

There is not, of course, a single HPS-informed view of science or of science education. There are two broad camps discernible in the literature: those who appeal to HPS to support the teaching of science, and those who appeal to HPS to puncture the perceived arrogance and authority of science. The second group, which includes most constructivists, stress the human face of science, the fallibility of science, the impact of politics and special interests, including racial, class and gender interests, on the pursuit of science; they argue for scepticism about scientific knowledge claims. For this group, HPS shows that science is one among a number of equally valid ways of looking at the world, it has no epistemic privilege; its supposed privilege derives merely from social considerations and technological success. This group includes those influenced by postmodernist philosophy, and certain sociologies of science.

Whilst I regard science as characterised by the three Rs – Reason, Realism and Rationality – my argument for HPS in science teacher education does not depend upon these positions. My own book on the subject is written from the standpoint of the first group mentioned above, the defenders of science, but it does embrace a number of the positions of the second group: science does have a human, cultural, and historical dimension, it is closely connected with philosophy, interests and values, and its knowledge claims are frequently tentative. This is just to say that science is more complex, and more interesting, than many simple-minded accounts might have us, and science students, believe. However none of these admissions need lead to scepticism about the cognitive claims of science.

Recent literature contains accounts of a number of HPS courses for trainee and practising science teachers. There is general agreement that in initial teacher training such courses should be applied or practical courses. Sending education students to a philosophy department to do ‘HPS101’ is not the best way to proceed. HPS courses for teachers should begin with problems, literature or material that teachers can see as pertinent to their own professional development, or to the development of HPS-informed classroom materials and programmes of study.

Gerald Bakker and Len Clark have written a text (1988) and designed a course (1989) around the concept of explanation. Students can immediately appreciate that science is about explaining things, and that teaching is also about explaining things. This idea provides a pedagogically relevant path along which historical, philosophical, and psychological matters can be traversed. Bakker and Clark deal with the distinction between science and pseudoscience, explanation and description, the covering law model of explanation, other models of scientific explanation and religious explanation. Science students are generally willing to read and think about these matters because they see their relevance to science. They can be led to investigate the current state of philosophical discussion about scientific explanation, which is well presented by, for instance, Philip Kitcher and Wesley C. Salmon (1989). Trainee teachers can also see the purpose of thinking about what it is to explain something to someone, and what it is for a pupil to understand something. The notions of understanding, explanation and reasons were central in the work of the philosopher of education Richard Peters, whose *Ethics and Education* (1966) argued for such notions as the hallmark of liberal education in contrast to mere training or indoctrination.

Ronald Good and James Wandersee (1992) have developed a graduate course on HPS for trainee science teachers. Central to their course are the ideas that: (1) the history of science should serve as an introduction to the philosophy of science; (2) the philosophy of science should be introduced in a non-technical way; (3)

both history and philosophy should be linked directly to science teaching. The focal question for the course is, what constitutes scientific progress? The course begins with Darwin's *Voyage of the Beagle*, in which Good and Wandersee identify twenty philosophical and methodological issues that students can identify or be presented with. Students then study Larry Laudan's *Science and Relativism* (1990), a Galileo-like dialogue between a pragmatist, relativist, positivist and realist. Students were able to develop a richer understanding of science, and produced HPS-inspired units of work for classes.

Arthur Stinner and Harvey Williams have developed a science education course that examines 'the major achievements of science as well as the practices of scientists throughout history'. Their students design science stories, one for each of the major historical epochs, that are then used in classrooms (Stinner and Williams, 1993).

My own course (Matthews, 1990), deals with two episodes in the history of science: the seventeenth-century revolution in astronomy and physics, and the nineteenth-century revolution in biology. The course is based upon selections of the writings of Galileo, Boyle, Newton, Huygens, Darwin and others.[8] They are 'heroes' in science yet have seldom been read by teachers who teach about them.[9] I have found, not surprisingly, that teachers appreciate the opportunity to read something of their work. As one teacher stated, 'teachers are hungry for this knowledge'. The philosophical issues – realism, instrumentalism, authority, reductionism, causality, explanation, idealisation – are dealt with as they arise out of the text. The text also provides the opportunity for contextualising the science; for discussing its intellectual, economic, religious, ideological contexts; and for considering the interaction between science and these broader contexts. There is ample opportunity to take up issues of internal/external history of science, and of the sociology of science. The idea is not to produce historians and philosophers of science, but to stimulate teachers' interest in the subject and give them enough training to identify HPS issues as they arise in the classroom, texts and curriculum.

These HPS-for-science-teaching courses could supplement more orthodox philosophy of education courses in science teacher education programs. Unfortunately, the orthodox philosophy courses often do not engage would-be science teachers, who often do not see their relevance to classroom practice. HPS courses wear their relevance on their sleeve, or at least on their course descriptions, and so this first hurdle to satisfactory progress is easily overcome.

Whose History? Whose Philosophy?

The history and philosophy of science has been discussed so far as if it is uncontroversial and settled, something on the shelf merely waiting for the instructor and student to pick up, and carry off to the science classroom. There may have been some grounds for this comforting belief when Scheffler originally penned his argument in 1970. It was a time when versions of Logical Empiricism and Inductivism were widely accepted as *the* Philosophy of Science. Ernest Nagel's *The Structure of Science* had then assumed something of canonical proportion since its original publication in 1961; Arthur Pap's *An Introduction to the Philosophy of Science* had been a standard text since its publication in 1963, as had Carl Hempel's *Aspects of Scientific Explanation* since its publication in 1965. And of course a generation of students had been reading Sheffler's own *The Anatomy of Inquiry* following its publication in 1963. There was a certain hegemony about Logical Empiricism, or the 'Received View', as Frederick Suppe referred to it in his 1973 *The Structure of Scientific Theories*, a book that, along with Thomas Kuhn's 1972 *The Structure of Scientific*

Revolution, began the destabilising of this comforting hegemony. The destabilisation has progressed a great deal in the past twenty years, as any perusal of the professional journals, or attendance at professional conferences, will attest.[10] Cultural historians of science – who, as we have seen, 'feel the need to defenestrate science, or at least take it off its pedestal' (Pumfrey, *et al*., 1991, p. 3) – are bitterly opposed to traditional historians of science. This debate among historians is mirrored, as we have seen, in the debate between realists and constructivists in the philosophy of science.

Clearly serious scholars disagree over many high-level topics in the history and philosophy of science. Most agree that central notions such as Rationality, Confirmation, Realism, Truth are not as straightforward as previously assumed in Logical Empiricist writing. Most sophisticated philosophers of science, when developing theories of science, try to accommodate the historical dimension of rationality, they try to be cognisant of the social and cultural dimensions of science, they try to recognise the human dimension of theory appraisal and decision making.[11]

My overall argument is that HPS discussion is *relevant* to, and *implied* by, much of the practice and theory of science education, and thus needs to be included in programmes of teacher education. My argument does not require commitment to any *specific* philosophy of science. Trainee teachers need to come to their own decisions about the specific topics – Galileo's use of mathematics and his debate with the church, the cognitive function of thought experiments, the claims of realism against empiricism, how to appraise one theory against others, and so forth. Most advocates of a liberal approach to science education share Joseph Schwab's dismay with science being taught as a 'rhetoric of conclusions', and wish to avoid teaching a rhetoric of conclusions about the history and philosophy of science. No matter how strongly an instructor holds particular views in the history and philosophy of science, a HPS programme requires that students themselves come to hold their own reasoned opinions on the subject. I happen to think that constructivism is flawed, and would like my students to also see this, but I would far rather them come to their own informed opinion on the subject, no matter what that opinion was. Bertrand Russell reminded us, if reminding is required, that a wise system of education 'would aim at making [students] think, not at making them think what their teachers think' (Russell, 1961, p. 401). In the same vein, Max Planck told his students that all statements in his lectures should be interpreted as questions, not as assertions. Of course neither Russell nor Planck are advocating that teachers should keep their light under a bushel; they certainly voiced strong and clear opinions on a range of professional and popular subjects. Their point is simply that teachers having voiced opinions and presented arguments, students should be encouraged to question, not to memorise.

The Australian researchers Ted Cawthron and Jack Rowell nearly twenty years ago wrote a comprehensive paper on the subject of 'Epistemology and Science Education' in which they concluded with a recommendation that has, unfortunately, been ignored:

> Clearly the teacher training institutions need to look more closely at these matters and to employ professional staff well versed in both the methodology and the philosophy of science. If possible persons who also have worked in scientific research with distinction for several years. Progress is not going to be very marked, as long as science education is left simply to practising teachers or administrators with no training in the philosophy and epistemological foundations of science. Length of classroom service is not an appropriate qualification for critical analysis on the epistemological level.

(Cawthron and Rowell, 1978, p. 51)

If this book results in Cawthron and Rowell’s argument being looked at afresh, then it will have served on of its purposes.

CONCLUSION

Constructivist influence can be seen in mathematics, social science, reading and literary education in New Zealand. It casts its shadow across the educational landscape. The problem is not, of course, confined to New Zealand. Constructivism, sometimes in its postmodernist and at other times in its feminist forms, is popular in university education, philosophy and literature departments all over the Western world. This has prompted the philosopher Michael Devitt to remark:

> I have a candidate for *the* most dangerous contemporary intellectual tendency, it is ... constructivism. Constructivism is a combination of two Kantian ideas with twentieth-century relativism. The two Kantian ideas are, first, that we make the known world by imposing concepts, and, second, that the independent world is (at most) a mere 'thing-in-itself' forever beyond our ken. ...[considering] its role in France, in the social sciences, in literature departments, and in some largely well-meaning, but confused, political movements [it] has led to a veritable epidemic of 'worldmaking'. Constructivism attacks the immune system that saves us from silliness.
>
> (Devitt, 1991, p. ix).

Devitt is correct in saying that constructivism attacks the immune system that saves society from silliness. If taken seriously constructivism does destroy society's capacity to judge true from false, sense from nonsense. Constructivism substitutes viability for truth, and sense-making for science, thereby undercutting the basis on which objective public knowledge can be built and identified.

Karl Popper recognised the socially corrosive aspect of constructivism, when he said:

> The belief of a liberal – the belief in the possibility of a rule of law, of equal justice, of fundamental rights, and a free society – can easily survive the recognition that judges are not omniscient and may make mistakes about facts ... But the belief in the possibility of a rule of law, of justice, and of freedom, can hardly survive the acceptance of an epistemology which teaches that there are no objective facts; not merely in this particular case, but in any other case.
>
> (Popper, 1963, p. 5)

Education systems have a responsibility to identify and transmit the best of our cultural heritage. Science is one of the most important parts of this heritage. Constructivist ideas rightly alert us to the complexity of scientific practice and its history, they do underline the creative and human dimensions of science, but on many interpretations constructivist ideas also trivialise science and its achievements. Further, by asserting unnecessary and unrealistic conditions for effective teaching, constructivists confuse and burden already hard-pressed and diligent teachers. And, constructivist ideas have unhappy consequences for culture as well as education.

It is notorious that people have for centuries thought that the grossest injustices, and the greatest evils, have all made sense. The subjection of women to men has, and still does, make perfectly good sense to millions of people and to scores of societies; explaining illness in terms of possession by evil spirits makes perfectly good sense to countless millions; the intellectual inferiority of particular races is perfectly sensible to millions of people including some of the most advanced thinkers. The list of atrocities and stupidities that made perfect sense at some time or other, or in some place or other, goes on and on. It seems clear that the appeal to sense is not going to be sufficient to refute such views, the appeal to truth which is independent of human desires or power, may be able, perhaps, to overturn such opinions. Certainly the interests of the less powerful and marginalised are not advanced by championing the view that power is truth; minority rights have always been better advanced by holding on to the view that truth is power.

I have argued that the good and useful parts of educational constructivism – teaching for understanding, finding out student ideas, engaging the learner, presenting science as social, creative and influenced by personal and community interests – are simply not novel, and need not commit teachers to the dubious epistemological, ontological and educational claims of constructivism.

Further it is glaringly clear that, for all its research output, there is precious little learning theory developed by constructivism. The 'alternative frameworks' research has generated thousands of articles about what children of different ages, in different countries, think about different scientific topics and phenomena. As a research programme it is wonderful, because it knows no bounds: there is always a new group in a new country, or culture, to administer a test to, or to interview about some scientific topic or phenomena. The most recent Leeds publication on the subject contains a list of about 900 research articles on British, Norwegian, French, German, Nigerian, New Zealand etc., children's ideas about Rocks, Growth, Water, Electricity, Sound and so on (Driver *et al.*,1994). However little learning theory emerges from this mountain of research. As the convenors of the 1992 King's College seminar asked: 'is there any great value in more researchers collecting more data about more phenomena from more groups of children in more countries?' (Black and Lucas, 1993, p.xi). Probably not.

There is also minimal pedagogical advice for teachers charged with teaching the content of science. For twenty years the constructivist mountain has shaken but has produced not much more than a classroom mouse. As Richard White, one of Australia's leading constructivists, has said 'research on alternative conceptions ... has not yielded clear advice about how to teach different topics' (White, 1994, p. 255). In my opinion the programme should now be put on the back burner, and attention paid to other pressing philosophical, pedagogical and curriculum matters.

I have been critical of constructivism in general, and especially of its influence in New Zealand. As with John Stuart Mill, I think that intellectual progress is made through debate and argument, and I hope these criticism have been clear enough to be useful. There are major educational and cultural matters at stake in this debate. If constructivism is a correct account of human knowledge, and the process of its social and personal development then, as constructivists say, major transformations in education are called for. However if these transformations occur in the name of a doctrine both erroneous in its philosophy, and deleterious in its social consequences, then New Zealand education, and ultimately New Zealand culture, will have been dealt a severe blow.

NOTES

Chapter 1

1. The interactions of science and philosophy in the scientific revolution are explored, and original texts provided, in Matthews (1989). Derek Gjertsen (1989) provides a nice introduction to the history of these interactions. Informative essays on the more general relationship between science and culture are in Holton (1967) and Holton and Blanpied (1976). Alan Cromer (1993) is an excellent and readable account of the multifarious impact of science on the development of Western culture.
2. Brooke (1991), Funkenstein (1986), Hooykaas (1972) and Mascall (1956) are four, among legion, general discussions of the interactions between Western science and religion. Moore (1979) is an excellent discussion of religious reactions to Darwin. The 'Galileo affair' is documented in Finocchiaro (1989). It is discussed in Langford (1966), Poupard (1987) and Redondi (1988).
3. For essays on science and Eastern religions, see Singh (1987).
4. The resolution of these debates is entirely dependent upon an understanding of the nature of Western science. See Hodson (1993), Stanley and Brickhouse (1994), Cobern (1993), Cobern (1993) and Matthews (1994, chap. 9) for some of the issues and literature.
5. See Passmore (1978), Holton (1993), Burnham (1987), Gross and Levitt (1994), and the essays in Kurtz and Madigan (1994) for discussion of these tendencies.
6. It is well known that without Hungarian-educated scientists there would not have been a successful U.S. atomic energy programme or rocket propulsion programme. Among some of the better known scientists were Zoltan Bay, Robert Bárány, Roland Eötvös, Theodore von Kármán, John von Neumann, Michael Polanyi, Leo Szilard, Edward Teller and Eugene Wigner. And of course there were significant Hungarian contributions to music, mathematics, philosophy and literature. All this is mentioned because the Hungarians were explicit in their regard for education and the importance of teachers. After the War, when the country and economy was in tatters, children successfully learned writing and mathematics using sand boxes which were smoothed out after each part of a lesson. The country had educated and dedicated teachers with which to begin the process of rebuilding. Even today, teachers of science in Hungarian primary schools (up to age 14 years) have to study physics for four years, a requirement unheard of anywhere else in the world.
7. Dr Derek Hodson, now a professor at the Ontario Institute for the Study of Education, was for a number of years at Auckland University and Dr Janet Burns has been for a number of years at Massey University. It is a matter of public record that these two researchers have not been included in the official 'loop'. Janet Burns, despite having a PhD in chemistry and occupying a room in the same Ministry of Education in which the *Draft Forms 1-5 Science Syllabus* was being developed, was barely asked to participate in its development or comment upon its progress. I was at the University of Auckland for two years (1992-93), and despite being the only science education professor in the country, I was not invited to participate in the Ministerial Advisory Committee on Science Education. There are various possible reasons why non-constructivists are not in the official loop of advisory committees, research-grant holders, policy development contract holders and so on, but one reason could be simply that they are not constructivists.
8. Copies of the 40 page circulated document, 'The Crisis of Truth in New Zealand Education', are available from Dr Harold Turner, 8A Peart View, Remuera, Auckland 5, New Zealand.

Chapter 2

1. See report 'Poor Language Skills Prompt Call for Compulsory Studies', in *Campus Review*, 13-19 October, 1994.
2. Jonathan Kozol's books – *Illiterate America* (1985), and *Savage Inequalities* (1991) – provide a chilling account of mass illiteracy, pathetic schooling and generations of children condemned to ignorance by the educational establishment supposedly responsible for their enlightenment. The books also contain references to the myriad literature and reports on the topics.
3. From a national survey conducted by the American Mathematics Teachers Association in 1987.
4. From a national survey conducted by the American History Teachers Association in 1987.
5. The classic report is *A Nation at Risk* published in 1983 by the National Commission on Excellence in Education. It began by saying that 'the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a nation and as a people'.
6. These tendencies are clearly, if sadly, illustrated in one Auckland University guide to essay writing. The staff member advises students, when dealing with quotations, to do all sorts of things, such as, say what the quote means to you, how do the words affect you, what message does the quoted passage have for present feminist and political issues and so on. Students are no where asked to say what the passage means in its own terms.
7. Dr Des Rainey of Auckland has related to me his unsuccessful attempts to have Division facts retained in the new Primary Mathematics Syllabus. An Education Department overseer of the curriculum wrote to him saying that children do not need to have recall of division facts because if they know multiplication, they can work out division from first principles. Thus children do not need to know automatically what 45÷9 equals, because if they pause they can work out the answer. This is simply making life, and mathematical problem solving, much harder for children, and contributing to the abysmal results catalogued in the ACE test.

Chapter 3

1. For instance Boyd (1984), Bhaskar (1975), Brown (1994), Devitt (1991), Glymour (1985), Harré (1970), Hooker (1987), McMullin (1984) and Schlagel (1986). Something of the history of debate between empiricists and realists in the history of science can be seen in chapter 8 of my 1994 book.
2. John Gilbert, an English science educator who has frequently worked with the Waikato group, is one of a number who have interpreted Kelly's significance for science education. See Pope and Gilbert, 1983.
3. Something of the history of New Zealand science education can be found in Ensor (1960), Jesson (1991), Massey (1980) and Ockleford (1966).
4. Once more this is not a unique failing of New Zealand constructivism: casual, unsupported (and often insupportable) remarks about the history and philosophy of science occur with depressing frequency in constructivist writing.
5. The idea of children's science was introduced in Gilbert, Osborne and Fensham (1982). Although it accords with child-centred pedagogy, it has the potential to trivialise science by suggesting that children are doing just what adult scientists do. This is far from the case.

The most recent book by Rosalind Driver and colleagues says, for instance, that 'The way in which science ideas are constructed by pupils reflects the nature and status of science as public knowledge' (Driver *et al.*, 1994). This is most problematic. They go on to assert the 'naturalness of science' thesis when they criticise teachers who present scientific thinking 'as a special sort of thinking that is fundamentally different from common-sense reasoning' (p. 7). Constant repetition of this assertion fails to address the problem of the historically late and very local emergence of Western scientific thought: if Western science is just commonsense, or even mature commonsense, why is it that it emerged so late in human history and why did it not emerge in all cultures? It is Aristotelianism which is sophisticated commonsense, not Newtonianism. The break with commonsense is what the scientific revolution of Galileo and Newton was all about.

6. References to most of the research can be found in the bibliography of *Learning in Science* (Osborne and Freyberg 1985).

Chapter 4

1. On this particular matter see Buckley (1971).
2. For references in this tradition, and its basic principles see, among others, Bantock (1981).
3. This problem is part of a larger one for the science education community. Although science educators, of necessity, have to engage with epistemological and psychological questions, most are not trained in philosophy or indeed psychology. The usual career path into university science education positions is a science degree, teacher training, teaching, then science education studies.

Chapter 5

1. In one place Ernst von Glasersfeld says that the year 1710 (the publication year of Berkeley's *Principles of Human Knowledge)* 'was a very good year'.

Chapter 6

1. Content free exams are a necessary consequence of a constructivist curriculum (where there is no guarantee that the same content knowledge has been taught to all students), combined with the need to evaluate students comparatively across schools in order to allocate higher education positions, scholarships and the like. The effect of 'content free' exams is to lock bright children into their dominant place in the system, at the expense of less bright, but hard working pupils. Content free exams are barely disguised intelligence tests, at which the bright will always excel even if they are lazy, and at which the ordinary will remain ordinary no matter how hard they work. And as 'brightness' is in part a function of the richness of a person's home life, content free exams legitimate and reproduce social class divisions. Hardly something that constructivists set out to do!
2. During my two-year period in Auckland I meet numerous good and enthusiastic teachers who despaired of the teacher-development courses they had attended. Many walked out, others endured to the end but said their precious time and school money was wasted.

3. These examples are discussed by Matha Nussbaum (1994).
4. The basic report on the wider issue of Maoris and New Zealand education, is W.A. Hirsch's *A Report on Issues and Factors Relating to Maori Achievement in the Education System* (Hirsch 1990).
5. Aspects of this debate, and discussion of the literature, are dealt with in Matthews 1994, chap. 9. See references in note (4) of chapter one.
6. Discussion of the legal and philosophical aspects of this trial can be found in Gilkey (1985), and Ruse (1989).
7. Wallis Suchting (1995) has made headway in understanding *how* to answer the perennial question of What is Science?
8. Why people feel driven to assert equality of achievement between cultures is itself interesting. It seems more sensible to say that some cultures do some things well and other cultures do other things well. European Jewry has had (but only since the mid-1800s) terrific success in fostering scientific talent, it clearly has had no success in fostering sporting talent. The Hmong people of South-East Asia have wonderful handicraft traditions but little achievement in technical areas. The medievals built gracious cathedrals, but did not master science. Some cultures have outstanding musical traditions, while other cultures barely rise above noise production.
9. For one guide to the considerable literature see Helen Selin's 1993 annotated bibliography. Another source is Eva Krugly-Smolska (1992).
10. Numerous books deal with the complex matter of the rise of modern science. Some particularly useful ones are Basalla (1968), Boas (1962), Bullough (1970), Harman (1983), Lindberg (1992), Lindberg and Westman (1990) and Wartofsky (1968).
11. Lewis Wolpert's recent book, *The Unnatural Nature of Science* (1992) is an excellent treatment of the disjunction between scientific and everyday thinking, while Alan Comer's book, *The Heretical Nature of Science* (1993) is a clear and enlightening treatment of the rise and chequered career of science in Western culture. Bronowski (1978) is one earlier and accessible discussion of the matters. The topic is well dealt with in Wallis Suchting's two articles, 'Notes on the Cultural Significance of Science' (Suchting 1994), and 'On the Nature of Science' (Suchting 1995).
12. *The Process of Education* is an educational best-seller and classic. It had its 23rd printing in 1994. Chapter Two of the book is tilted 'The Importance of Structure'.
13. The document largely avoids the central question of tailoring science curricula to the intellectual abilities of students, and embraces the egalitarian ideas of 'Science for All'. In its opening pages it does say that 'School and classroom programmes in science need to identify and nurture students with special abilities in science. When used flexibly, the curriculum offers talented students both acceleration and enrichment' (p.12) But there is no attempt to identify what talented, or university-bound students, might learn, nor is there any attempt to come to grips with the issue of whether this group should be studying a different type of science programme than those students who have no ambitions in science.
14. The Core Knowledge Foundation was established by E.D. Hirsch of the University of Virginia. He is the author of *Cultural Literacy* (1987).
15. Some university science departments complained that their comments on the drafts were not attended to. The head of one physics department wrote to me saying, 'Two people from my own Department of Physics were indeed consulted although they were both left with the feeling that their contributions were

rejected out of hand since they did not exhibit the appropriate level of political correctness'. For outsiders to comment on the underlying principles of the curriculum would require something in the order of a book like this, or a complete course on science education. This is an unrealistic expectation.

Chapter 7

1. This section is taken in large part from chapter six of my Routledge book, *Science Teaching: The Role of History and Philosophy of Science* (Matthews 1994).
2. An accurate and reliable clock set going on the Greenwich meridian so that at precisely noon, the clock showed noon, could then be used to establish longitude on any journey. One needed only to see what time was on the clock when noon was ascertained by the sun being directly overhead. The earth rotates 3600 in 24 hours, so if the clock read 11am at noon, it meant the position was 15^0 west of Greenwich.
3. There is no adequate history of the medieval pendulum. Lynn White (1962, pp. 117, 172-173), and (1966, p.108) discusses some aspects of the topic. Sarlemijn (1993) discusses the role of the pendulum in Newtonian mechanics.
4. Some of the details can be found in Matthews 1994, chapter 6.
5. This vital idealising feature of Galileo's physics is discussed in Koertge (1977) and McMullin (1985).
6. See the Drake translation of del Monte's *Mechanics* in Drake and Drabkin (1969), where he is described as the greatest mechanician of the sixteenth century.
7. Discussion and references can be found in White (1966, p.109).
8. Much has been written on Galileo's 'discovery' of the law of parabolic motion, and the relevant place of mathematics and experiment in its justification. Ronald Naylor (1976) provides an early examination of the matter, much of the related literature is reviewed by David Hill (1988).
9. This claim needs to be nuanced as there was, beginning with Aristotle himself, a lively tradition of the 'mixed sciences' in the Aristotelian tradition. Astronomy and optics made extensive use of mathematics, but they did not substitute mathematics for science, and did not replace the phenomena with an equation. On this issue see Lennox (1986).
10. This is translated in Fermi and Bernardini (1961).
11. The cycloid curve had been studied by Galileo and his pupil Torricelli. Huygens recognised that, for large amplitudes, the effective length of the pendulum had to be shortened with respect to the amplitude; a cycloid enabled this to happen.
12. Some of this development can be seen in Kline 1959, ch. 18.
13. Much has been written on Copernicus and the origins of the modern world view. Some of the more substantial works are Blumenberg (1987), Boas (1962) and Kuhn (1957).
14. For discussion of the clock as a metaphor in culture and philosophy see Laudan (1981).
15. See Aldridge (1992) for the rationale of the curriculum proposal, and discussion of the pendulum. The absence of historical and philosophical considerations reflects the unfortunate gap in the US between science educators and the community of historians and philosophers.
16. On this matter, see Wisan (1978) and McMullin (1978).
17. The central document is Galileo's 1615 *Letter to the Grand Duchess Christina* in Drake (1957). Many books deal with the issue, one being the Vatican symposium on Galileo's Trial (Poupard 1987).

18 A nice sequence of such lessons can be seen in Ekstig (1990). A second-year university science student, training to be a secondary teacher, wrote the following about the Ekstig article:

> I am a student who did not do physics for the Higher School Certificate and only did half a year of university physics before dropping out after failing the mid-year exam. I have heard myself say many times that I dislike immensely and cannot do physics. After reading this article I wonder at my negative attitude. Basically I have never given the subject much of a chance, but on the other hand I have never heard it or read it presented in such an interesting and relevant way ... The thing that amazed me was that I actually understood ... Because my exposure to physics generally left me confused and I was convinced that it was beyond me.

Chapter 8

1. Parts of this chapter are taken from chapter 10 of my 1994 Routledge book.
2. At the University of New South Wales in 1991, a TER (tertiary entrance rank) of 94/100 was required for entry to Law, a TER of 55 was required for Education. At some of the newer universities, the entry TER for Education has dropped below 50.
3. In 1992 in the state of New York, with a population of 18 million, there were only twelve physics graduates in teacher education programmes. In Louisiana, with a population of 4 million, there were none.
4. Arguments for the place of foundation studies in teacher education can be found in the contributions to Tozer *et al.* (1990).
5. His paper 'Philosophy and the Curriculum' was originally presented at the state University of New York at Brockport in 1970, it was revised for presentation at a conference on the philosophy of education sponsored by the Council for Philosophical Studies in 1971. It was published in his collection titled *Reason and Teaching* in 1973. The paper has been republished, with an 'Afterthought', in the journal *Science and Education* (vol. 1, no. 4, 1992), a journal devoted to the contribution of history, philosophy and sociology of science to science education..
6. See for instance the contributions to the anthologies edited by Matthews (1990), Hills (1992) and Herget (1989, 1990).
7. See, for instance, the research of Koulaidis and Ogborn (1989), Lederman and Zeidler (1987), Lederman (1992), and Rowell and Cawthron (1982).
8. Most of the scientific revolution texts used have been published in Matthews (1989), the Darwinian texts are in Appleman (1970), and secondary papers on HPS and science teaching are in Matthews (1991).
9. In twenty years of teaching hundreds of biology graduates I have found about ten who have read any of Darwin's work; among physics graduates I have yet to find one who has read any of Galileo's work.
10. The classic history of the post-Kuhnian changes in philosophy of science is Harold Brown's *Perception, Theory and Commitment: The New Philosophy of Science* (Brown 1977).
11. Two recent introductory texts in philosophy of science that reflect the historical and social dimensions of science are Salmon *et al.* (1992) and Gillies (1993). One can be sophisticated in these matters without being a constructivist.

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