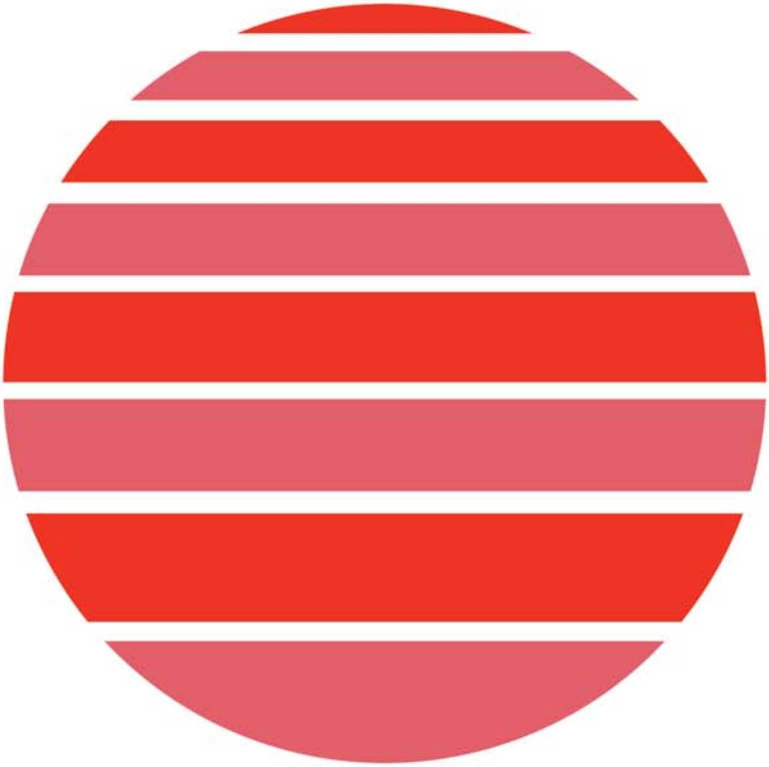
Contemporary Analysis in Education

DEVELOPMENT AND DILEMMAS IN SCIENCE EDUCATION



Edited by PETER FENSHAM

Development and Dilemmas in Science Education

CONTEMPORARY ANALYSIS IN EDUCATION SERIES

General Editor: Philip Taylor

6 *Education and Cultural Pluralism*
Edited by Maurice Craft

7 *Language and Learning: An Interactional Perspective*
Edited by Gordon Wells and John Nicholls

8 *Educational Research: Principles, Policies and Practices*
Edited by Marten Shipman

9 *Schooling and Welfare*
Edited by Peter Ribbins

10 *Assessing Educational Achievement*
Edited by Desmond L. Nuttall

11 *Education, Recession and the World Village*
Edited by Frederick M. Wirt and Grant Harman

12 *Social Education: Principles and Practice*
Edited by Chris Brown, Clive Harber and Janet Strivens

13 *Education and Society Today*
Edited by Anthony Hartnett and Michael Naish

14 *Education and Youth*
Edited by David Marsland

15 *Economics and the Management of Education: Emerging Themes*
Edited by Hywel Thomas and Tim Simkins

16 *The Changing Primary School*
Edited by Roy Lowe

17 *Mathematics in Primary Education*
Edited by Michael Preston

18 *The Primary School Teacher*
Edited by Sara Delamont

19 *Educating Teachers: Changing the Nature of Pedagogical Knowledge*
Edited by John Smyth

20 *Political Education in Britain*
Edited by Clive Harber

21 *Informal Primary Education Today: Essays and Studies*
Edited by Alan Blyth

22 *Language and Literacy in the Primary School*
Edited by Margaret Meek and Colin Mills

Contemporary Analysis in Education Series

Development and Dilemmas in Science Education

Edited by

Peter Fensham

ROUTLEDGE/FALMER
(A member of the Taylor & Francis Group)
London • New York • Philadelphia

First published 1988 by The RoutledgeFalmer

Reprinted 2002 by RoutledgeFalmer
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Transferred to Digital Printing 2005

RoutledgeFalmer is an imprint of the Taylor & Francis Group

British Library Cataloguing in Publication Data

Development and dilemmas in science
education.
1. Schools. Curriculum subjects. Science
I. Fensham, Peter J. (Peter James), 1927-
II. Series
507'.1

ISBN 1-85000-350-5
ISBN 1-85000-351-3 Pbk

Typeset in 10/12 Bembo by
Mathematical Composition Setters Ltd, Salisbury, Wilts.

Contents

General Editor's Preface Philip Taylor vii
Foreword ix
Chapter 1 Familiar but Different: Some Dilemmas and New Directions in Science Education
Peter J. Fensham 1
Chapter 2 What Counts as Science Education?
Douglas A. Roberts 27
Chapter 3 Teachers in Science Education
John R. Baird 55
Chapter 4 Learners in Science Education
Richard F. Gunstone 73
Chapter 5 What Children Bring to Light: Towards Understanding What the Primary School Science Learner Is Trying to Do
Bonnie L. Shapiro 96
Chapter 6 Theory into Practice I
Richard T. White 121
Chapter 7 Theory into Practice II: A Constructivist Approach to Curriculum Development
Rosalind Driver 133
Chapter 8 Role of Language in Science Education
V. G. Kulkarni 150
Chapter 9 Practical Work and Science Education I
Sunee Klainin 169
Chapter 10 Practical Work and Science Education II
Avi Hofstein 189
Chapter 11 Gender and Science Education I
Svein Sjøberg and Gunn Imsen 218

Chapter 12 Gender and Science Education II
Jane Butler Kahle 249
Chapter 13 The Dilemma of Science, Technology and Society Education
Joan Solomon 266
Chapter 14 Broadening the Aims of Physics Education
Harrie M. C. Eijkelhof and Koos Kortland 282

Notes on Contributors 306

Index 309

General Editor's Preface

In what has come to be one of the most important tracts in education, *What Knowledge is of Most Worth?*, Herbert Spencer argued and urged that the knowledge of most worth is science. 'Its truths', he said, 'will bear on human conduct ten thousand years hence', and though it is hardly one hundred since he said that, there is little to suggest that he will be proved wrong. He went on to say that 'rational knowledge has an immense superiority over empirical knowledge' and because of its sheer rationality, he claimed, science was *the* knowledge to learn. He also gave other reasons including practical and social ones.

Today there is no need to argue that Science should be seen along with mathematics and one's own language as a key subject of schooling. It has become self-evident.

Even so there is much to be debated and discussed when it comes to *Science Education* which is the subject of this sharply acute, ably constructed and up-to-date reader. It really is a compendium of the best kind: informative, comprehensive and likely to be an important stimulus to thought and action. It leaves little in the teaching of science at all levels unexamined. One might have expected such under Peter Fensham's able editorship. That he has actually achieved it must be a cause for great satisfaction among science educators everywhere and of sincere congratulations to him and the many contributors whose work has made possible a book of great worth.

Philip H. Taylor
University of Birmingham, 1988

To Christine
whose support and tolerance
made possible the encounters that
have created this book

Foreword

In choosing authors for the chapters of this book I had a number of criteria in mind. Firstly, from my knowledge of them as persons or from their work and other writing, I believed that they had important things to say about science education. Secondly, they responded to the framework or description of the reality of science education I suggested for the book and which I have argued for in the first chapter. Thirdly and as a corollary of this sense of reality, they are science educators who, in their own ways, take the content of science seriously, see learners as active constructors of scientific meaning, and/or have recognized the importance of social context and effect as neglected aspects of science education.

Others could also have met these criteria but within the limits of editorial coherence I wanted a range of national contexts from which the chapters would be written. In the end, nine such contexts are included and among these are India and Thailand. In my own numerous contacts with science educators from both industrialized and less industrialized countries I have been increasingly aware in the 1980s that some of the best organization, effective practice, and most original insights and innovations are occurring in some of the latter countries. Even with the substantial efforts that UNESCO has made over many years to provide international communication in science education, the developments in science education in the second group of countries (the world's majority) are much less well known than they should be.

In inviting the authors I asked them to focus their contribution on a particular theme although I knew full well that each of them sees science education more holistically. The selection of these themes for the chapters was, for me (and no doubt for the authors), a fragmenting of an interactive whole. To avoid the themes appearing to be definite discrete components of science education (and for several other reasons) I chose to seek alternative views on themes rather than multiply the themes themselves. In this way, readers will have reinforcement of some aspects and a sense of different emphases and connections about others. They will also more readily be able to discern how the tradition from which an author comes, the context in which they live and work, and the literature on which they draw, shapes the way they address and respond to current issues in science education.

In my opening chapter I juxtapose the sense of importance school science education is now assuming with a realistic appraisal of what we have learnt in the twenty-five years since 1960 when it was also very much front stage as far as the curriculum of schooling was concerned. I suggest that science education is now much more complex and interesting but also that it is much more difficult than we thought in 1960. In the process of this rather too grand scale account of a number of contemporary dilemmas facing science education and of some of the interesting possibilities that seem now to be worth exploring, I touch on the various themes that are taken up in the subsequent chapters.

Douglas Roberts (chapter 2), using a normative perspective, addresses the question, What counts as science education? In doing so, he sets science education firmly in a social context within which at any time there are a diversity of stakeholders so that this context is, in fact, not one but many. Each context has its purpose for science education and this leads to the stakeholders for each one choosing to emphasize a particular set of science learnings. Science curriculum policy, he argues, is always a compromise among these various curriculum emphases, and as such presents dilemmas and even sharp conflicts for the teachers who are required to implement it. One of the emphases Roberts identifies is a science, technology and decisions one that is taken up later in the book by Solomon, and by Eijkelhof and Koortland.

John Baird (chapter 3), on the theme of teachers, argues strongly against the simplistic view that certain behavioural competences in teachers will lead to successful learning in science and for a more complex picture of what and how teaching and learning are determined. Accordingly, he does not see the emphasis on the teacher's overt behaviour in the classroom that has so often been put by researchers and teacher educators (both pre- and in-service) as helping us to understand the teacher's role in science education. Instead he sees some recent developments in metacognitive research and in particular, action research projects in which classroom teachers are active collaborators, as important new directions for science education research which could lead to improvements in science teaching.

Dick Gunstone in chapter 4 on learners in science education has addressed the quite enormous literature that is now available (after only about ten years of research) on learners' views about natural phenomena and the conceptions they hold of the scientific description of these that are usually included in school science. He avoids yet another review of this work (since a number are available) by relating and contrasting this recent work, with its generally constructivist orientation towards science learners, to the much older Piagetian line of research on learners. In two other parts of this chapter he pursues and teases out the images of learners and of science that these constructivist researchers are generating and the ways of bringing about conceptual change in classrooms that are consistent with their theoretical position about teaching and learning.

Bonnie Shapiro, without referring to metacognition, and Rosalind Driver who does, both provide in their chapters (5 and 7 respectively) examples of the sorts of research in science classrooms that Baird is advocating. Shapiro, through her own case study of children in a primary class studying light, provides insights into the thinking of young learners of science in context that goes much further than the alternative frameworks research has been able to do with its concentration on science concepts, albeit methods that have so often involved individual learners.

Driver and Dick White (chapter 6) have both written on 'Theory into Practice'. Driver outlines in some detail her interpretation of the constructivist view of learning that she (and most of the other authors) acknowledges as the theoretical base for the projects and practices her group is undertaking in the Children's Learning in Science Project in Britain. She describes the way they have worked with science teachers to develop approaches to teaching a number of common science topics that take seriously constructivist principles and what this sort of research has shown us are commonly held conceptions about these topics.

White's chapter, also from a constructivist base, moves more freely into a less theoretically defined future, or rather one characterized by chains of theory-practice-revised theory, etc. He uses the series of research projects which he has shared with Baird and a number of science teachers to argue a way forward that could lead to realistic research in science education that would not present teachers (as has been so common in the past) with credibility and applicability gaps, because it has been so largely developed and validated by teachers like themselves.

In chapter 8 Kulkarni presents a Third World perspective as he addresses some of the language problems confronting his country, India, as it seeks in its post-colonial independence to universalize education and in particular science education. He outlines various sociolinguistic problems that are starkly obvious in his context but which do have their counterparts in all societies where such social differentials are often overlooked. A number of studies he and his colleagues have undertaken are described and these are characterized by practical interventions that have made positive contributions in what could have seemed most daunting situations.

Sunee Klainin from Thailand (the discoverer of some remarkable findings about girls and science education) and Avi Hofstein from Israel are the authors of chapters 9 and 10 on the theme of practical work or the role of laboratory in science education. This theme is associated with some of the most fascinating dilemmas of science education. Klainin reminds us of the accepted place the laboratory has had in school science education in some countries for a century at least, and of the central role it was meant to play in the new curricula of the 1960s and 1970s. Nevertheless, as she and Hofstein point out, practical work was ignored by many of the evaluators of these innovations, and when it was considered the findings were discouraging. Both authors, however, argue that the new bases do now exist for teachers to use practical work in their science teaching in ways that promote sorts of learning that are readily understood by teachers and students, and in addition that contribute strongly to the latter's enjoyment of the subject. Klainin, in particular, emphasizes that good assessment procedures are now available (Hofstein was a contributor to these), and that this is a major difference from the earlier period of the so-called activity-based science curricula.

Svein Sjøberg and Gunn Imsen from Norway and Jane Butler Kahle from the USA, in chapters 11 and 12, address the concerns that are now very widespread about gender factors in science education. The former focuses on the male image of science and how that image affects the teaching and learning of science in schools and the aspirations about science that girls and boys have. From the two chapters, enough about current participation patterns, achievement and aspirations emerges to justify the general concern that science education in the schools of many countries is a major factor for, rather than a corrective to, the disadvantages girls and women so regularly face in contemporary technological society. Kahle draws on some recent research literature to suggest ways in which the image of science and science education could be changed. Sjøberg and Imsen combine social and cultural analysis with some very intensive psychometric data from girls and boys in Norway to point to the depth of the problems. They are able, however, also to point to some features that are encouraging as efforts to redress these imbalances occur. Their data on the contributions more girls in science and technology may make to their practice and image are particularly interesting.

Science education and technology education are so often now spoken of together that the Science-Technology-Society theme was obviously an important one to include. In chapter 13 Joan Solomon from Britain traces several of the main influences for the current interest and press to introduce STS courses in schools. In doing so, she points to the tangle of objectives and variety of conceptions of STS that already exist. She goes on to look at what we know of students' reception and learning of such courses. Harrie Eijkelhof and Koos Koortland from the PLON physics project in the Netherlands describe in some detail in chapter 14 the evolution of that project team's thinking about the way science learning can, or should, be related to the impact its science content as technology has on members of a society. This description of an actual example of the development and use of STS science materials (particularly from such a pioneering group as PLON) provides a helpful, practical case to relate to Solomon's more general chapter. This sort of counterpoint occurs several times in the book and is a happy additional outcome of the strategy of asking two authors for most of the themes.

Books like this rarely rest on the shoulders of their authors alone. Behind my own efforts in science education there has been, over many years, the very direct support of numerous colleagues and several secretaries in the Faculty of Education at Monash University. My thanks go to each of them and to their counterparts at the University of Leeds where most of the final editing was done. No doubt each chapter author has had their own support from similar persons and the final manuscript is, in that sense, theirs as well as ours.

Peter J. Fensham
February 1987

1

Familiar but Different: Some Dilemmas and New Directions in Science Education

Peter J. Fensham

Introduction

At a time of general economic restraint and cutbacks in education, a Learning in Science Project was set up in New Zealand in 1979 for three years that has so far been extended to nine, and in 1982 Britain's Department of Education and Science established the complex and expensive Secondary Science Curriculum Review. Almost before the last staff, lingering into the 1980s after a longish period of depression in American science education, had left their posts at the National Science Foundation, this body, and a number of others in the USA, were reviewing and reporting on the state of this field in schools and establishing new projects to remedy its deficiencies.

In 1984 UNESCO's Regional Office for Asia and the Pacific was asked by its member states to make 'Science for All' a top priority area for development over the remaining years of the decade. Australia, one of these member states, has lagged behind the efforts that, for example, Thailand, Malaysia, Indonesia and the Philippines have been recently putting into science curriculum developments. In 1986, it did, however, begin to review its school science education seriously and several projects with strong government backing have now begun. Canada, a country with many similarities to Australia, undertook a very extensive review of its school science education earlier in the 1980s and its provincial governments are now responding with a number of new curriculum initiatives.

This list of renewed national concern and activity about science education in schools could be substantially extended. It will, however, suffice to testify to a widespread political and economic concern, and to a willingness on the part of authorities to provide funds, personnel and other resources for the improvement of science education in schools.

This situation, with its positive climate of support, should at first sight be a very pleasing one for science educators. To many of us it does, however, present one very general dilemma and a great number of more specific ones as the various aspects of what should be done in this field of curriculum development are considered.

The general dilemma relates to the fact that the 1960s and early 1970s are so recent that the very similar rhetoric and enormous effort that went with the science curriculum reforms of that period have not been forgotten. Even today's younger science educators, through their own training, are aware of these similarities because the documentation of that earlier period is so extensive and because its residues in the schools have been their own experience of learning and teaching science at school. Furthermore, for any who are prepared to turn to the histories of science curricula (see, for example, Layton, 1973, and Jenkins, 1979, in Britain; Hurd, 1961, and Bybee, 1977, in the USA; and Fawns, 1987, in Australia) there is ample evidence that the generation of the 1960s (let alone the 1980s) was certainly not the first to expect great things for learners at school from science education. There is a strong sense of déjà vu.

The great burst of activity in curriculum development in science began in Britain and the USA in the late 1950s and continued there till the early 1970s. It did much to give a new meaning to curriculum development and to professionalize its procedures. These new conceptions spread beyond science to many other parts of the programme of schools as curriculum development centres or departments rapidly became established as part of the educational scene. Nor was the notion of 'curriculum development' confined to these two countries for it rapidly spread to many others. Some of them did not, however, embark on truly indigenous curriculum development till the 1970s. In a number of cases this delay was due to the fact that a form of educational imperialism occurred. That is, materials for the school populations of Britain, the USA or France were exported, with or without minor adaptation, to the school systems of other countries where quite different sociopolitical and socioeducational needs and demands prevailed. These differences were very apparent in the countries of the Third World that had only recently gained their political independence. Nevertheless, it was the education systems of some of these (under persuasive advice from now 'foreign' consultants) that, in a number of instances, took up these new materials more extensively than did the schools in their countries of origin. Countries like Australia and Canada, which in some senses were socially similar to the USA, also made extensive use in some of their centralized provincial school systems of materials from the National Science Foundation's projects in the USA. It can now be seen, however, that this period of direct importation of science curricula, even in these countries, distorted the educational scene and inhibited more appropriate local developments.

As I wish in a number of ways to relate the present and future prospects for science education to the situations, events, and products associated with this earlier period of interest and activity in science education I shall refer to it as 'the 1960s' knowing full well, as I have just indicated, that some of its effects on science curriculum reform were more evident, in fact, in the 1970s.

In the various rationales that were provided for the activity in science education in the 1960s and in those for the 1980s two similar targets are addressed. These are a scientifically-based work force and a scientifically literate citizenry.

The stress on the former is quite evident. The National Science Foundation's 1983 report 'Educating Americans for the 21st Century' sees school science education as important to produce the scientific and technological professionals who will enable the USA to compete economically with Japan. This is so reminiscent of the Rickover report in the 1960s although the threat then was the USSR and in a political sense rather than an economic one. Likewise, in their reference to the latter target, the statements for the two periods are also quite similar, generally presenting a picture of more science education, along with more science and technology, as being unquestionably good things for societies to have.

It is surprising to find this recurrence of such an uncritical stance about science in society in the 1980s, but the NSF report referred to above is indeed as devoid of reference to the disastrous state of the environment and the contributions of American industry and technology to it as were its 1960s counterparts. Reading its arguments for 'making American science education the best in the world' (!!) is as if Rachel Carson, Paul Erlich and Barry Commoner were part of science fiction, and there have been no problems with acid rain, species depletion, waste disposal and nuclear accidents in the twenty-five years since the 1960s.

So it is both what the contemporary reports say about science education and what they omit that heighten the sense of déjà vu and contribute to it being a dilemma for the efforts that are being made to improve the teaching and learning of science in schools.

It might be (and it is a possibility that would be quite consistent with the framework I present a little later in this chapter), that this déjà vu simply means that science education is now being challenged to do for the coming generations of school learners what was achieved by the reformers in the 1960s. In other words, the societal conditions have now so changed that what were good solutions for science education in the 1960s are now no longer appropriate.

Alas, the dilemma cannot be so simply dispelled for this interpretation assumes that solutions were found in the 1960s to the problems of science education as they were perceived at that time. Unfortunately the record of achievement from the 1960s does not support such a position. Quite literally, by the late 1970s in some of the countries which first embarked on these reforms to their science curricula in the 1960s their managers had run out of excuses and ideas. Initially it had seemed that all that was needed were first class suggestions for what science education in schools should be like and an adequate supply of carefully prepared supporting materials (texts, films, laboratory exercises, etc). Even when these proved unattractive to the majority of teachers in countries where they were not mandatory, or were distorted almost beyond recognition where they were, the momentum of this approach was so great that most of the available resources continued to go into revisions of these first materials or into other attempts to design 'the package' of science education that could, when developed, be handed over to teachers to use in their schools. Along with this 'package' approach to improving science education a number of countries put considerable resources into upgrading their school science facilities in the form of more and better laboratory provision in schools and/or the introduction of ancillary technical staff. Somewhat belatedly, attention then began to turn to teachers as 'the problem' in relation to the implementation of these improved science courses, and by the early 1970s in-service education courses to induct teachers into the intentions of the new science curricula were being conducted on a large scale in a number of countries. Almost invariably these courses were conducted away from the teachers' schools, in centres like universities and colleges. The perception of the 'teacher as problem' was of the teachers' own interactions with the curriculum package. The contextual features of their particular schools and classrooms were not seen as relevant.

In the latter half of the 1970s a number of major evaluations of these attempts at solutions to the problems of science education were conducted. In Britain, Harding *et al.* (1976) investigated the implementation of the products of the Nuffield science projects, and in the USA, several separate evaluations of the effects of the NSF projects were carried out (Hegelson *et al.*, 1977; CSSE, 1978; and Research Triangle Institute, 1977).

These, and evaluations from many other countries, were shared at an international conference in Israel (Tamir *et al.*, 1979). When the range of problems that were tackled and when the extent of the implementation of the proposed solutions are taken into account, a reasonable summary would be that success was at best patchy.

In Australia, one of the countries were schools throughout the country had been equipped with new laboratories and technical assistants, there was evidence that there was less practical work in senior secondary science than earlier. Only two of the nineteen countries participating in the first IEA study of science education (Comber and Keeves, 1973) chose to include practical tests despite the centrality they were giving to the laboratory in their curriculum rationales.

I am not saying that there were no educational achievements as a result of the 1960s efforts. Clearly there were a number, and it is important to recognize the sorts of changes that were possible since these may be the easiest sort to change again. Equally, however, for the good of what might be achieved in the next decade, we would be foolish not to recognize that we now know that effective science education in many of its aspects is much more difficult to achieve than the reformers of the 1960s ever dreamt.

In an attempt to dispel the déjà vu dilemma, I intend in this chapter to do three things. First I shall provide a framework for discussing what was happening and what was achieved in the efforts of the 1960s. Next I will use it and some of the features of the contemporary scene to argue that the present and the more immediate future are very different from the 1960s. Finally I shall point to some of the more specific challenges and developments that seem to me to be important to heed if real advances are to be achieved on a wide scale in school science education.

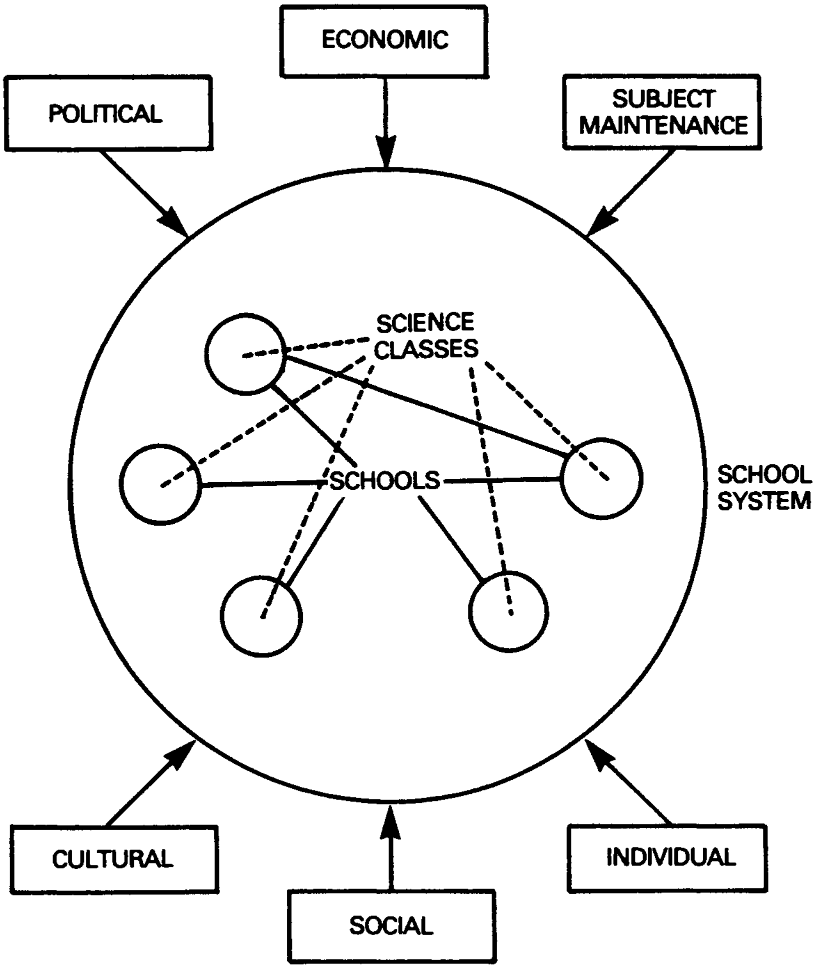
A Sociopolitical Framework for Science Education

The curriculum movement of the 1960s has rightly been criticized (for example, Young, 1971, and Waring, 1979, in Britain; Gintis, 1972, and Apple, 1979, in the USA; and Bourdieu and Passeron, 1977, in France) for often behaving as if schooling, and science education in particular, takes place in a social and political vacuum. The export of science curricula to which I referred earlier is an example of this attitude. The fact that science does have some 'universal' aspects was used to justify and make possible the transferability of science curricula across national boundaries. Another example of this 'social vacuum' attitude to science education is the 'desocializing' of science and science education that occurred in many of the projects. References to scientists as persons and citizens contributing to our understanding of nature and its manipulation in their own societies almost disappeared in the first wave of these new curriculum materials, as did any serious reference to industrial and science applications of science. There was accordingly little or no discussion in these new science courses of the social implications and consequences of science (Fensham, 1976). As one further example, I can refer again to the naivety project after project displayed in assuming that implementation in complex social systems like schools was essentially only a function of the science education 'package' or of this package and its interaction with a science teacher, abstracted from the social realities of her/his school and classroom.

Historians and curriculum theorists, like those mentioned above, have helped us to see that schools are established by societies to fulfil a number of educational functions. The curriculum, in its parts and in its totality, is the instrument to serve these functions as well as being the field where the competition between these societal demands on schooling is resolved. In figure 1 I have tried to indicate some of the societal demands that compete for priority in a science curriculum's emphases (see also chapter 2).

The sciences, particularly the physical sciences, in many societies, are gateway subjects that filter the relatively few students who are allowed to

Figure 1: Competing societal demands on schooling and science education



move into certain professions of high status, societal influence and economic security. Because of the societal power associated with these positions, we can call this a *political* demand on schooling. Again, a limited but definite number of persons with scientific skills and expertise are needed in any society to maintain and expand a variety of aspects of its economy. This is an *economic* demand. Scientists, particularly in research institutions and universities, are now a powerful faction in society with a major interest in *maintaining their subject* as an elite and important field. They are thus keenly interested in having the schools begin the process of reproduction of the sciences as those in higher education define them. In addition, there are clearly many ways in which all *cultures* and *social life* are now influenced by knowledge and applications from the sciences. Science education can assist people to have a sense of control rather than of subservience and to take advantage of what science in these ways has to offer them. The fascination of scientific phenomena and the role of human inventiveness in relation to them offer much potential for school science education to meet the demands of its learners for *individual* growth and satisfaction.

If there are, as I suggest (and figure 1 portrays), a number of different societal demands on the science education that schools provide, it is not surprising that not all will be equally well met. Indeed the possibility exists that the curriculum of a science education that meets one or several of these demands may not serve the interests of the others. Recognition of this possibility, unfortunately, is still quite rare in the reports and policies of the 1980s as it was in the 1960s. Without it, some critical implications for science curriculum are likely to be missed in the decision making for the current reforms in science education, just as they so largely were in the development and implementations of the 1960s reforms.

Curriculum Competition in Action

An example of this competition for science education at school is how it relates to the two distinct targets of a scientifically-based work force and a more scientifically literate citizenry (Fensham, 1986a). The former, related to the top three demands in figure 1, is needed so that societies and economies can keep pace in a world where scientific knowledge and technology are being exploited in a rapidly increasing way. The latter, more related to the lower three demands in figure 1, consists of those who should benefit from the personal and social applications of science and who will be prepared to respond appropriately to changes of a scientific or technological kind.

At first sight it can appear that the achievement of either of these two targets will also be a contribution to the other. That is, as the first target is met and exceeded, school science education is on the way to meeting the second.

Or, if the second is met to any significant extent, on the way the first will be achieved. Just such a simplistic cooperative view of the interactions of societal demands and the curriculum of schooling operated in the reforms of the 1960s. Under the advice and guidance of well meaning university scientists and encouraged by some slogans about the nature of learning that were current at the time, the 1960s projects aimed at inducting all learners at school into the world of the scientist. Not surprisingly, it was the research scientist they chose as their 'model scientist'. There was, it seems, a genuine belief that both targets would be met if all children, in appropriate ways for their level of schooling, were to learn some of the ideas and some of the ways these sorts of scientists use to describe and explore the world. All (or as many as learnt successfully) would have gained a degree of scientific literacy, and enough of them would be interested to continue on to become the specialist work force of tomorrow.

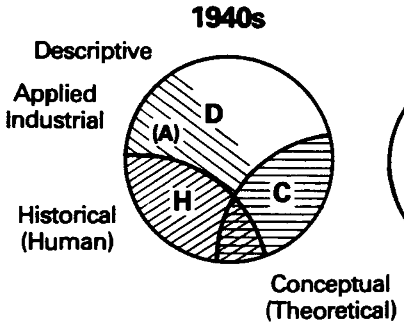
Right from the start, however, it is now clear that the apparent even-handedness in the statements of intent gave way in practice to the interests the first target represents. The first curricula to be redesigned in the USA, Britain, Australia, Canada, Thailand, Malaysia, etc. were those for the upper secondary school — the very level where only those, from whom the specialist work force will be drawn, are present at school. By giving priority to the curricula for this level, the projects were explicitly rejecting the interests of the target group of scientific literacy since very few countries in the 1960s had a majority of each age cohort still at school at this level or even most of them studying science.

Under their terms of reference which included updating the content of school science education (long overdue as a result of the Second World War) these first projects did suggest radical changes indeed to what should be learned. The changes did not, however, take the form of a massive infusion of recently acquired knowledge from the sciences or even of their contemporary explanations or issues. Rather, these courses and their guiding papers emphasized the structure of the knowledge of the major disciplinary sciences and the ways it can emerge from their empirical studies.

It so happens that part of this intended new content for learning namely, the concepts and the relations between them, was essentially what, by this time, had become firmly entrenched as what university courses in science were about. In general it is only these aspects of the proposed new content that gained emphasis when the new courses were implemented in the schools. The considerable extent of these changes in content can be seen in figure 2 which shows a content analysis of senior chemistry courses over forty years (Fensham, 1984).

We should perhaps not put all the blame for this outcome of the 1960s reforms on the projects or their scientist advisers. It is not their fault directly that the scientific reasoning that leads to these concepts and the way models of

Figure 2: Changes in the content of school chemistry 1940-1980 and some features of the secondary school age population



explanation evolve from empirical findings in science, and the processes of scientific enquiry were largely ignored by secondary teachers and secondary science examiners. After all, few undergraduate science courses in which these teachers are trained put much weight on these philosophical, historical or syntactical aspects of the science disciplines.

It is possible, however, in terms of societal demands, to understand what happened once the two choices, of senior secondary courses as the first to be reformed and of the research scientist as model, had been made.

Subject maintenance meant an emphasis on continuity of content for science learning between school and higher education. It meant the choice of content that would ensure that students moving from school to further studies in science in higher education would have a familiarity with the concept words and relations between them that would be used and further developed in the first years of specialist training. If they succeeded in becoming scientific professionals their apprenticeships in research or in technology would, in due course, provide them with the syntax of their science, so that it was not necessary earlier in school or undergraduate science.

The political and economic demands then turned out to mean that a sufficient supply of science students for the nation's needs is important but that an oversupply is not to be encouraged. On a number of occasions since the 1960s school science has, in both more and less industrialized countries, succeeded in oversupplying the number of students who had 'successfully' completed studies in science and mathematics. Rather than being welcomed as a contribution to scientific literacy these oversupplies have been embarrassing to governments since the students involved have themselves seen their success essentially in vocational terms, and have expected places in the expensive technical facilities of higher education and in employment (unlike their counterparts in the humanities) that makes use of their specialized training in ways the economy of the time could not afford.

Accordingly, the science curriculum at these levels was required to be such that they did prepare enough students for future studies but that they also provided a spread of learning achievements among them so that selections can be easily and evidently done.

This selective requirement has been reinforced by other changes in school curricula in this period which have increasingly given the sciences (along with mathematics) the responsibilities for the sieving and sorting processes that employers and the next levels of education impose on all school systems, and that were in the past served by language studies.

We can summarize the outcome of these demands on school science education and of the priority given to the target of the specialist work force by listing the characteristics of learning content that has prevailed since the 1960s reforms in most, if not all, school systems as the science content of 'most worth' for learning.

(a) It involves the rote call of a number of facts, concepts and algorithms that are not obviously socially useful, rather than allowing obvious social usefulness to determine what scientific information should be so learnt.

(b) It involves so little familiarity with many of these concepts that their scientific usefulness is not experienced, rather than concepts being learnt in the process of exploring their usefulness in scientific and common life.

(c) It involves concepts that have been defined at high levels of generality among scientists without their levels of abstraction being adequately acknowledged in the school context so that their consequential limitations in real situations are not adequately indicated.

(d) It involves an essentially abstract system of scientific knowledge, using examples of real objects and events to illustrate this system, rather than using scientific knowledge to elucidate life experiences and social applications of science.

(e) It reduces the role of practical activity in science education to the enhancement of conceptual learning rather than being a source for learning essential skills and gaining confidence in applying scientific knowledge to solve real societal problems.

(f) It gives a high priority (even in biology) to quantitative aspects at the expense of understanding of the concepts involved.

(g) It leaves to the later study of scientific disciplines in higher education or employment the balance, meaning and significance that is lacking in (a) to (f).

(h) It determines its 'knowledge of worth' by selecting those concepts and principles that are logical starting points for learning the increasingly abstracted knowledge that is such a dominant component of what lies ahead in the continued study of the sciences.

It will be obvious from the way I have described these characteristics that other sets with quite different priorities and outcomes for the nature of science curricula are possible and may, prima facie, be more consonant with a science education for scientific literacy.

Before considering what has happened at the other two broad levels of schooling where science education occurs, some of the other outcomes of the senior curricula since the 1960s should be noted.

The quantitative achievements of school science education with respect to the first target are the more remarkable since they occurred during a period of unprecedented expansion of higher education in many countries. The supply of sufficient students from school who have been formally 'successful' in science has, however, turned out to be not wholly satisfying to the subject maintenance demand of science faculties in higher education. Since the 1970s a number of senior university scientists have been expressing dissatisfaction with the quality of the preparation in science of this elite group of school students. Furthermore, using rather different criteria, a number of studies that have involved first year university students have seriously questioned the quality of their preparatory learning in science. Rote recall seems to characterize their conceptual learning rather than depth of understanding or ability to use it to explain (see for example, Champagne, Gunstone and Klopfer, 1985; West, Fensham and Garrard, 1985; Brumby, 1981; and Hewson, 1981).

A number of the new curricula for a senior secondary study of the sciences (particularly those required for further study) have proved to be unattractive to students. Despite the increased numbers of students studying them (and hence meeting the first target as described above) there has been a decline, in a number of countries, in the proportion of the students at school choosing to study physics and chemistry when these subjects (or science more generally) cease to be part of a compulsory curriculum. This lack of attractiveness has been particularly marked in some sectors of the school population such as girls and students from some social groups who are now participating much more in these levels of schooling than they were in the 1960s.

On the other hand, certain other senior science curricula that were developed later in the 1970s along rather different lines and which could have been more attractive to more students have been strongly opposed, when it has been suggested that they become the primary source of the science education of students at these levels. In other words, there has been strong suspicion of the logical possibility that if science curricula at schools were successful for widespread literacy in science they should be an adequate base from which to draw those going on to be science professionals. Accordingly, minor revisions that leave unchanged the essential character of the disciplinary senior science courses have been allowed to occur but the more radical changes that the alternative science courses represented have not been approved. There is, thus, a great deal of evidence, at least in many of the more industrialized countries, that the curriculum of science education for the latter years of secondary education has been shaped to service the top three demands of figure 1 to the exclusion of the interests of the lower three.

Lower Secondary Science Education

The earlier years of secondary education (roughly for students with ages from 12 to 15) were already, for many countries when they embarked on the 1960s reforms, part of compulsory schooling and so involved the student populations for whom the second target is relevant. They may, however, have been differentiated into streams that already had different ends in view. For example, in Britain about 20 per cent of this age group were in schools that had the senior levels of science education that have just been discussed at length, and the other 80 per cent were in schools without such senior levels and where there was an expectation that students would move more directly into the work force after age 15 or so. In contrast, in the USA there was no such streaming by schools but a streaming by choice of subject could occur that affected the science education of many students.

It is thus not surprising that two sorts of science curriculum projects were developed for the lower secondary years in the later 1960s once the priority projects for the senior level were sufficiently far advanced.

In Australia, there was JSSP, a course of study that was made up of sequential modules and in each year there were some for chemistry, physics, biology, earth science and astronomy. There was also ASEP (sequential only in the intended learning demand of some of its units) which drew its content in a more integrated way from a wider range of sciences. In Britain, there were Nuffield Combined Science and Nuffield Secondary Science, a pair paralleling in their emphases the two Australian ones. Likewise in the USA, there were IPS and ISCS in the first category, and ESCP and Environmental Science in the second.

At these levels the interests of the two target groups were more evenly reflected in the development resources. Most of these projects claimed that they were aiming at scientific literacy but the restricted choice of science content and its conceptual emphasis in the first category ones were evidence of their continued subservience to a sense of being preparatory to the courses at the senior level. Wherever streaming of these students has occurred it has also been notable that the curricula of the first type have almost invariably been used with the more 'academic' streams or, in other words, with those most likely to go on to further study in science. From the point of view of scientific literacy for the majority this may have been reasonable although it did mean that the group of more able students (many of whom in the end would not continue with science) would not learn the much broader sense of science that the curricula in the second category contained. In the dynamics of a period when the purpose of these years of schooling changed rapidly as more of each age were retained in increasingly comprehensive secondary education, such a comfortable co-existence could hardly last. The two sorts of science courses have been hierarchically ranked as to worth so that, from the available evidence at the end of the 1970s, it is reasonable to conclude that the mainstream science curricula in these earlier years of the secondary school were characterized by learning emphases that are not very different from those listed above for senior secondary science. The content for learning in science had again been shifted from a descriptive and socially practical science to a more conceptual one. The focus for learning had been largely moved, as at the senior levels, from natural phenomena and other objects of scientific study and application to the concepts scientists use to describe them.

Primary School Science Education

When we turn to science education in the primary school we find a very different scene. Here, far removed from the point of schooling where the upper three demands in figure 1 have relevance, the explicit intentions of the projects of the 1960s were to contribute foundations to the scientific literacy of learners. In doing this, primary schooling would also provide a broad base of learners confident in, and ready for, science in the secondary school.

Almost all the projects for this level of schooling were, however, still within the *induction into science* approach referred to above. A range of learning outcomes consistent with this approach was used as the basis for developing materials. Some, like Concepts in Science and the Science Curriculum Improvement Study, continued to try to marry conceptual instruction with the science skills of observing and questioning phenomena and of applying concepts. Others played down specific concept learning in the interests of the acquisition of so-called science processes. Some of the latter followed Nuffield Junior Science in Britain and ESS in the USA and aimed to encourage any processes that enabled general enquiry and exploration of natural phenomena to occur. Others followed the lead of Science — A Process Approach in the USA or Science 5–13 in Britain and set out to develop a set of clearly defined reasoning skills. The phenomena in association with which this learning took place were very much secondary in importance to the skill or 'science processes' themselves. Some of the topics suggested by Science 5–13, for example, as appropriate ones to interest learners of these ages also, as it happened, served to indicate that these skills were not particularly 'scientific'. (They could certainly be applied to social phenomena and they are perhaps better described as being means of rational enquiry or problem solving.)

Both sorts of projects encountered great difficulties of implementation because of the lack of confidence and knowledge of science that teachers at these levels almost universally have. With so little understanding of the science concepts themselves, it is not surprising that teachers found it very difficult to teach how and why they emerge in science. On the other hand, teaching the 'content-free' processes required great logistical skills in classroom management, and did not seem to be science to these teachers (or to their learners' parents) for whom science was a body of information they had failed to master during their own education.

Even on the criterion of 'preparing for the next stage' these approaches to primary science education 'failed'. The concepts, in the rote form in which they were largely taught, were topics that already had established places in secondary curricula, and the process skills were largely ignored by secondary teachers who did not require them in their students for learning the factual and conceptual knowledge of secondary science.

In a few countries a less separate approach was taken to the inclusion of science in primary schooling. Thus in Thailand it is meant to be part of a major segment of the timetable called Life Experiences. This does relate it to more socially relevant phenomena but in practice, in the hands of primary teachers, this has often reduced science to just a few more facts or definitions to add to the social content of these topics with which these teachers feel more comfortable and more familiar.

At a level of schooling where the influence of the political and subject maintenance demands on science curricula might well be expected to be low, they have reappeared through the attitudes primary teachers and the secondary teachers have towards what was proposed as learning of worth in science.

Nevertheless, as a result of the efforts of the 1960s, science has become more clearly established as a formal part of the overall learning that children are expected to have in these primary years. There are, however, few reports from any countries that would suggest that we have yet found in science education the analogue of the situation in mathematics. That is, everybody outside primary schools — secondary mathematics teachers, parents, employers, administrators — identify with and welcome the teaching of the basic mathematical operations on numbers as wholly appropriate for primary schooling. Primary teachers, too, accept this as their responsibility and their only problem is to fulfil it effectively.

Primary teachers seem generally, despite the effort of all the projects of the 1960s and early 1970s, to have been confused and not convinced about the role of science in the education of the primary learner. In their practice of what is now often a formal requirement they rarely seem to identify with the optimistic contention of one of the earliest pioneers in the 1960s who claimed that science education would be the easiest subject to teach in the primary school. He argued that it was the only one that almost all children were prepared for before they start school, namely, they could observe things and orally report with accuracy what they saw!

Different Learners for Science

In most countries there have been quite significant changes since 1960 in the socioeconomic characteristics of the school populations for whom science education is now seen as possible and necessary. This is particularly obvious for secondary schooling which, in so many countries in the intervening years, has moved from an elite to a mass phenomenon. However, for science education the changes have also arisen from quite major shifts in a society's perception of who should participate in, and benefit from science education. Thus, the primary and lower secondary levels of schooling are affected as well as the higher levels of secondary in both more and less industrialized countries. They stem from a push by parents who see more education as a means of societal gain for their children, and a pull from governments which have encouraged students to stay longer at school for more general education, for more relevant skill training, and to reduce the costs and embarrassments of youth unemployment (a widespread phenomenon since the mid-1970s).

The multicultural character of the school population is now recognized in a number of European and North American countries and in Australia, New Zealand and Israel. This population change has arisen as a result of national economic demands that led to employment policies in the 1960s and 1970s that involved the parents of these students. The children of the immigrant families that take these sorts of risks and initiatives often bring attitudes and cultural expectations to learning in general, and to science in particular, that present quite new challenges to teachers most of whom come from more educationally established sectors of the society.

Particularly in the last decade as the feminist movement has gained renewed vitality, there has been a consciousness and a concern that science education has been a gender biased (in favour of boys) feature of schooling. While this concern is most evident in countries that have had a Protestant Christian tradition, a similar gender bias is obvious in many other countries. Indeed, in only a small number do girls and boys participate equally at school in the physical sciences — the gateway subjects to scientific careers — and in even fewer (Thailand is an interesting case) are their achievements comparable.

In 1960, participation of the children of the poorer families in upper or elite secondary education (where science education mainly occurred) was still, in quite a number of countries, essentially restricted to those who gained scholarships. Since then the proportion of students from lower income families has increased dramatically, but this rise is often not yet reflected in science education. This is a matter of serious concern when the changing nature of work and employment prospects are considered. Mass secondary education is itself partly a product of the reduced opportunities for traditional skilled and unskilled youth employment. Unless those, who would in the past have left school to enter the skilled and unskilled trades, participate more equally in science education at school, they will find themselves, despite more schooling, still at a disadvantage later in life as society and its employment opportunities become more and more technically derived.

These great changes in the culture, gender and class of school populations for whom effective science education should now be available mean that the societal realities of the 1980s and beyond are quite different from the ones in which the reform movement of the 1960s occurred. If those, who are now responsible for, and concerned about, the quantity and quality of school science education, can be persuaded that what they seek should be shaped and implemented as a function of these realities then the déjà vu dilemma will be dispelled. Furthermore, there will be some hope that some of the promising new directions that are already being trod (a number of which are outlined in later chapters) will have some chance of gaining mainstream recognition as science education. As a start we shall need to recognize that the two targets need their own forms of science education and that the second, with its concern for all learners, is the key to the first rather than the first being the key to the second as was the way in the 1960s reforms.

More Specific Dilemmas in Science Education

Limited Access to Experience

In 1960 school science education was outdated and static almost everywhere. By the late 1980s a majority of the world's countries have experienced major reforms or revisions of their science curricula.

Despite its extensiveness, the readily available international literature on science education does not reflect the richness of these experiences. The great bulk of the shared literature (curriculum materials, exhortative writing, evaluation reports and research studies) comes from a few countries that have English as their first language. Furthermore, some of these countries, such as the USA, Britain and Australia, have degrees of curricular freedom in their educational systems that render much of their curricular debate irrelevant to the majority of countries where the educational systems and hence curricula are more centralized.

Accordingly science educators face two dilemmas. The first is how to sort out from the available literature the ideas and outcomes that may apply to their own schooling contexts. This is not easy when so much of this literature has assumed that the contexts of origin are transferable or does not even recognize that context is important. All science teachers have some degree of freedom in what and how they teach but there are very significant differences in the way external constraints like national or more local curricula, examinations and available facilities constrain or encourage the exercise of this freedom. Failure to identify these constraints and encouragements in most of the reporting has made the transferability of much useful experience more difficult than it should have been.

The second dilemma is the sheer unavailability of most of the world's experience of science education since 1960. Only small fragments of it are available for sharing, either because only a few of the reports and materials are translated, or because there is little educocultural support for such information to be made mutually available. This dilemma is particularly unfortunate since the time sequence for the reform of science education in a number of less industrialized (and less publicized) countries has turned out to be advantageous. To begin with they have confronted, and hence recognized, more revolutionary societal changes in schooling whereas the changes in industrialized countries have been more evolutionary and hence less obvious. Then they have been in a position to learn not only from the ideas that influenced the well known projects of the 1960s but also from their success and failure in practice. Furthermore, at least in some of these countries, there has been access to a wider range of sources and expertise than was available to the earlier projects. These sources include the internationally available literature on science education (surprisingly unavailable in parts of the USA and Britain to judge by the citations of some authors in these countries), regional and international conferences, international documents and sources such as UNESCO (more widely known in the developing world than in the developed world), study tours, consultancies and staff development. It is not really surprising then, with these advantages, that some excellent developments have taken place.

The two IEA studies of comparative science education bear testimony to the quality of the developments in Japan. Thailand has provided very clear structural support for its efforts in curriculum development and that country's remarkable achievements in relation to the gender dilemma seem to be in large part due to this well planned aspect of their implementation (Fensham, 1986b).

We need more details about what lies behind these and the many other successes that are known to exist but are not yet in an exchangeable form.

Language and Culture

In the 1960s, as will be apparent from a number of things already referred to, the social and cultural context of the learners outside the school was not a factor of concern to the curriculum developers. Perhaps they reasoned that, if science itself had universal or transcultural characteristics, education in it would be equally so. On the other hand, it is more likely that, implicitly, these first developers built into their materials the language and examples that stemmed from the sub-culture they shared with their essentially middle class students.

Gardner's (1971) pioneering work on *Words in Science* in Papua New Guinea and Australia (later repeated in the Philippines, Israel and Britain) began to show the differential advantages that some students have as a result of their facility with the language used in science classrooms. Much of this stemmed from what can be described as the 'middle' words of science discourse. These are not the invented and technical words of science but the many words like 'solution', 'pour', 'energy', 'burn', 'agent', 'volume', 'because', 'so', etc. that have meaning in everyday discourse that is different from, or more varied than it is in science.

The links between language and science education have turned out to be an exciting field for research and a number of studies have now shown that the language of learners' cultures can raise problems for their learning of science. These problems are particularly acute and obvious in societies where the language of learning in school is different from the language used at home and in the wider society. Furthermore, because so much of modern science has been developed in Western countries its thought forms, concepts, and concomitant language are consonant with the languages of these societies. For example, most of these will have words that distinguish 'heat' and 'burn', and 'dissolve' and 'melt', but this is not so in many other societies where it has not been important to have such distinctions in the language. Some of these languages are, on the other hand, much richer than the Western languages in descriptive words for familiar objects, but this too can become a handicap when the scientific description and categorizations of them involve fewer, or even quite other characteristics.

These problems of language are, however, by no means confined to 'bilingual' situations. The many studies of children's conceptions in science have often reported the ambiguity that learners encounter between everyday and scientific usage of words and ideas (Osborne and Freyberg, 1985). Sutton's (1979) work on metaphors in science education, and his and Schaefer's (1979) interest in what they call the 'burr' model of science concepts have also contributed to our understanding of how language and culture can blur the precision of the sciences and hence interact strongly with their learning.

Lemke's (1982) sociolinguistic work on discourse in science classrooms has opened a window on how analogy can be both a powerful aid and a barrier to learning science. A few other reports have hinted that there may be major differences (and hence learning differentials) in the way students from different social class or ethnic backgrounds respond to the language of enquiry and of explanation as they are used in teaching science.

In 1981 Wilson produced a bibliographic guide to more than 600 studies since 1960 that related some aspect of the social and cultural context of learners to their science or mathematics education. There is no doubt that if we are serious about science education at school contributing to scientific literacy or to better understanding of its concepts, much more attention will have to be given to the role of these sorts of social and cultural factors.

The Role of Affect in Science Education

Most of the research on the learning of science has assumed that it is predominantly a cognitive process. Affect has been, however, of considerable interest as an accompanying learning outcome. Gardner (1975) put some order into the study of attitudes to science that students acquire as a result of science studies at school, and the findings of a number of well conducted studies are now available. A disconcerting number of these show that there is not a ready link between cognitive learning in science and a positive attitude to science. Indeed, it seems that often the longer students have studied science at school the more their attitude to it declined. The unpopularity of some of the sciences in secondary school has already been mentioned. Such negative attitudes to science in school are damaging to both targets of science education. Once again, curriculum developers in the 1980s have to face the evidence of a dilemma that was blissfully absent in the 1960s. Then it was generally assumed that learners would respond positively to 'good' curriculum materials and through their learning of science based on them acquire a strong affect for and an appreciation of science.

In 1985, Gardner (and Lehrke and Hoffman) edited the proceedings of a conference at IPN in West Germany that brought up to date the many ways that science as a learning outcome has been explored in the decade since his earlier work. Affect certainly continues to be of considerable interest as a learning outcome since it is likely to be an indicator of these future citizens' responses to science. There is also concern that the relative unpopularity of science in school does lead to social inequities in the outcomes of schooling and to a threat to the supply of the specialist work force.

Apart from the oft-reported positive contribution that active participation in small groups in practical work can make, much less attention has to date been paid to the role of affect in the learning process itself. A number of the leading cognitive researchers, such as Novak (1981), White and Tisher (1986) and West and Pines (1983) have drawn attention to its importance but, as yet, have not undertaken or reported studies that give others a sense of how it should be incorporated into learning.

Some of the reports of gender differences in interest are suggestive for science education. Harding (1983), for instance, draws heavily on Head's (1979) findings in suggesting and designing science education that is likely to be more gender balanced, and others have recently reported projects which change either or both the classroom context and the social examples that are used to teach science.

Minssen and Nentwig (1983) and Snively (1987) have reported two small but intriguing studies of affect in action. They share an unusual emphasis on the affect learners have for the objects they are learning about in science. The former made use of the very different attitudes he found that German students displayed to various chemical materials and to the shapes in which they were presented. The latter sought to build into science lessons about the seashore for primary children a recognition of several sorts of affective dimensions her research suggested different learners used when they thought about this complex object of study. We need many more studies of affect in action in the next few years if we are to harness it as the major factor it undoubtedly is for improving science education.

New Directions for Science Education

In the chapters that follow many of the new directions in contemporary science education that are interesting and promising are described. It will suffice therefore at this stage to mention two that relate to two areas in which quite major changes occurred as a result of the reform movement in the 1960s. As I said earlier, areas where change has occurred before may be areas that hold out more hope for change again.

New Content for Learning

One of the achievements of the 1960s that has been noted earlier is the major redefinition they gave to the content for science learning in schools and hence to what became its 'knowledge of worth'.

The new conceptual emphasis in the content for learning was, however, by the mid-1970s, being criticized from many sides. Reference has already been made to dissatisfactions about the quality of the conceptual learning. Another set of criticisms came from those who were concerned with the impact of science on society and with the social relevance of its learning to learners at school. That is, the a-social nature of the science content of the 1960s curricula was seen to be inappropriate in the face of the internationally recognized *Environmentale Problematique* and the technological realities of society (including the many new biomedical ones that are questioning public views of such fundamental concepts as birth, death and the biology of human relations).

It is both important and pleasing to be able to note that both these and other sorts of criticisms have now progressed beyond the polemical stage. Science educators, out of their own analyses of the outcomes of the 1960s, have recently developed a number of different schemes that define alternatives for the content of school science education. Furthermore, a number of current curriculum projects are promoting these quite new sorts of objectives as learning of worth for science at school

Some of these objectives are based on new analyses of the nature of science and science education (see, for example, Hodson, 1985; Millar, 1988; and Kass and Jenkins, 1986). Others recognize that knowledge in the sciences is a socially powerful way of knowing about natural objects and phenomena but it is nevertheless only one of the ways that various groups in society know about and deal with them (see for example, Fensham, 1983; and Osborne and Freyberg, 1985). Yet another group have given a new prominence to the interfaces between scientific knowledge and society (see Aitkenhead, 1986; Zoller, 1985; Brumby, 1984; and Eijkelhof and Koortland in chapter 14).

It is interesting to note that a number of these redefinitions of possible science content have recognized the discreteness of some of these objectives and hence their need of distinct recognition in the curriculum and its supporting materials. There is no doubt they will need their own recognition in the structure of schooling if most of them are not to be submerged by more traditionally powerful ones.

Each of these redefinitions of the possible content of school science education contributes to the idea that science at school should be recognized as a rich and much more variegated source of human knowledge and endeavour than it usually is at present. They also imply that a wider range of appropriate and recognizably distinct aspects of science need to be selected and converted into a pedagogy that makes up the curricula of school science education if they are to be effective for most learners. The basic steps in this process are epistemological tasks of a major order. They are also, I suspect, such radical ones that they are quite beyond the groups of university professional scientists to whom we have hitherto turned as sources and for legitimation. The intensity of the *induction into research science* of these sorts of scientists has been such that it is almost impossible for most of them to set it aside and give adequate value to other ways of encountering science. Elsewhere I have described my own attempts to step outside the chemistry into which I was inducted and to see anew how my field of science is about people and products and raw materials, rich colours, smells and scents, and other social properties of matter (Fensham, 1984).

I have argued that school science education after the 1960s has been essentially a form of *induction 'into' science*. The suggestions being made for it now in the 1980s are more aptly described as being a learning *'from' science*. These two curriculum processes are fundamentally different. In the first, teachers who have themselves been inducted into an acquaintance with some of the conceptual knowledge of science attempt to repeat the first steps of this process with their students. In the second, science teachers, as persons with some familiarity and confidence with the corpus of science, act as couriers between it and their students. As these students move through school their experiences in society (home, community and school) change and they encounter new situations to which science can contribute. It is these student needs that should determine, in the second process, the messages that the teacher couriers bring as science education to their lessons.

A number of quite new ways of defining science learning are now available that leave the 1960s behind. Some of these have already been translated into new materials and new sorts of ways of teaching. How rapidly and to what extent these will achieve normative status in school science is yet to be determined but it does seem that some of them would serve better the new and different societal imperatives that schools now face. They will, however, need more than their intrinsic merits to survive the competition between the differentially powerful interest groups. Structural supports will be essential. The form in which education in the sciences is made available and is required in schooling is one such critical support. The examinations, in whatever form they exist, are another since they so largely determine, for each school population, what is the 'knowledge of worth' in science.

New Notions of Curriculum Development

Science education in the 1960s led to new conceptions of curriculum development. Although a number of the recent projects seem to be following similar conceptions, that is, they will culminate in a 'package for better science teaching', a number of others are quite different. These, compared to the 1960s, give much more centrality either to the teacher, or to the teacher and the learner in their conceptions of curriculum development. Teacher development is what these projects interpret curriculum development in science as primarily being. It is interesting, however, to compare the rather different views they have of teachers and learners in the process of science education. Some still decontextualize teachers and see them as either deficient in science knowledge or in certain teaching competencies, and set up projects to remedy the deficiency. They pay no attention to the learners who thus are also perceived as essentially without context and effectively as 'tabula rasas' as far as science knowledge is concerned.

Others recognize that teaching science is not divisible into 'teaching' and 'science' in such a simplistic way and are attempting to assist teachers to see that the teaching of a science concept needs to be related to the ways learners (and teachers) conceptualize the phenomena it describes. The new 'didactics' approach in Sweden (Marton, 1985; Andersson, 1987), some of the CLIS projects in Britain (see Driver in chapter 7) and the large project at Stanford (Shulman, 1986) in the USA are different examples within this category.

Some other projects now rest on a still more complex view of the teaching/learning process. Not only is the teacher 'teaching science' but she/he is also teaching learners what it means to be 'learning science'. The work of Novak at Cornell and White at Monash has helped to shape this view and some examples of the sorts of curriculum development that follow from it appear in chapters 3, 4, 5 and 6.

A common feature of some of these approaches is networking of classroom science teachers. This particular reconceptualization of curriculum development is an encouraging development as it does suggest that its proponents are heeding the effects of the divorce, so apparent in the 1960s reforms, between the development of a curriculum and its materials, and its implementation subsequently in classrooms. It is also saying that the contexts of the classroom and the school in which the science teacher works are important features that again were quite discounted in the 1960s. Networking implies that groups of science teachers need to be brought into association with each other and with the curriculum developers for the sharing of ideas, information and experiences. It also leads to a more realistic recognition that teachers need time and support from outside themselves if such sharing is to bring about changes in their behaviour and in the learning of their students.

References

AIKENHEAD, G. (1986) 'Collective decision making in the social context of science'. *Science Education*, 69, 4, pp 453–75.

ANDERSSON, B. (1987) *Chemical Reactions*, EKNA Report No.12, Molndal, Institute for Pedagogy, Goteburgs University.

APPLE, M.W. (1979) *Ideology and the Curriculum*, London, Routledge and Kegan Paul.

BOURDIEU, P. and PASSERON, J-C. (1977) *Reproduction in Education, Society and Culture*, London, Sage.

BRUMBY, M. (1981) 'The use of problem solving in meaningful learning in biology', *Research in Science Education*, 11, pp 103–10.

BRUMBY, M. (1984) *Issues in Biology*, Melbourne, Nelson.

BYBEE, R. (1977) 'The new transformation of science education', *Science Education*, 61, 1, pp 85–97.

CHAMPAGNE, A.B., GUNSTONE, R.F. and KLOPFER, L.E. (1985) 'Effecting change in cognitive structures among physics students' in WEST, L.H.T. and PINES, A.L. (Eds) *Cognitive Structure and Conceptual Change*, New York, Academic Press.

COMBER, L.C. and KEEVES, J.P. (1973) *Science Education in Nineteen Countries*, International Studies in Evaluation I, International Association for the Evaluation of Educational Achievement, New York, Wiley and Son.

CSSE (1978) *Case Studies in Science Education*. Urbana-Champaign, CIRCE and CCC, University of Illinois.

FAWNS, R.A. (1987) *The Maintenance and Transformation of School Science*, PhD thesis, Clayton, Monash University.

FENSHAM, P.J. (1976) 'Social contention in chemistry courses', *Chemistry in Britain*, 12, 5, pp 148–51.

FENSHAM, P.J. (1983) 'A research base for new objectives of science teaching', *Science Education*, 67, 1, pp 3–12.

FENSHAM, P.J. (1984) 'Conceptions, misconceptions, and alternative frameworks in chemical education', *Chemical Society Reviews*, 13, 2, pp 199–217.

FENSHAM, P.J. (1986a) 'Science for all', *Educational Leadership*, 44, 4, pp 18–23.

FENSHAM, P.J. (1986b) 'Lessons from science education in Thailand: A case study of gender and learning in the physical sciences', *Research in Science Education*, 15, pp 92–100.

GARDNER, P.L. (1971) *Words in Science*, Melbourne, Australian Science Education Project.

GARDNER, P.L. (1975) 'Attitudes to science: A review', *Studies in Science Education*, 2, pp 1–41.

GARDNER, P.L., LEHRKE, M. and HOFFMAN, L. (1985) *Interests in Science and Technology Education*, Kiel, IPN.

GINTIS, H. (1972) 'Towards a political economy of education', *Harvard Educational Review*, 42, 2, pp 70–96.

HARDING, J.M. (1983) *Switched Off: The Science Education of Girls*, York, Longmans for the Schools Council.

HARDING, J.M., KELLY, P.J. and NICODEMUS, R.B. (1976) 'The study of curriculum change', *Studies in Science Education*, 3, pp 1–30.

HEAD, J. (1979) 'Personality and the pursuit of science', *Studies in Science Education*, 3.

HEGELSON, S.L., BLOSSER, P.E. and HOWE, R.W. (1977) *The Status of Pre- College Science, Mathematics and Social Science Education: 1955–1975, Vol.1, Science Education.*

HEWSON, P.W. (1981) 'A conceptual change approach to learning science', *European Journal of Science Education*, 3, pp 383–96.

HODSON, D. (1985) 'Philosophy of science, science and science education', *Studies in Science Education*, 12, pp 25–57.

HURD, P. (1961) *Biological Education in American Secondary Schools, 1890–1960*, Colorado, Institute of Biological Science.

JENKINS, E. (1979) *From Armstrong to Nuffield*, London, Murray.

KASS, H. and JENKINS, F. (1986) 'Normative perspectives on the nature of curricular knowledge in chemistry', paper presented at annual meeting of National Association for Research in Science Teaching, San Francisco.

LAYTON, D. (1973) *Science for the People*, London, Allen and Unwin.

LEMKE, J. (1982) *Classroom Communication of Science*, Report to N.S.F./RISE:SED R79–18961, (ERIC:ED222–346).

MARTON, F. (1987) 'Towards a pedagogy of contents', Publication No. 4, Department of Education and Educational Research, Mölndal, University of Gothenburg.

MILLAR, R. (1988) 'What is scientific method and can it be taught? in WELLINGTON, J.J. (Ed) *Skills and Processes in Science Education*, London, Methuen.

MINSSEN, M. and NENTWIG, P. (1983) *Journal of Chemical Education*, 60, pp 476–8.

NATIONAL SCIENCE FOUNDATION (1983) *Educating Americans for the 21st Century*, The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, Washington, DC, National Science Foundation.

NOVAK, J.D. (1981) 'Effective science instruction: The achievement of shared meaning', *Australian Science Teachers Journal*, 27, 1, pp 5–14.

OSBORNE, R. and FREYBERG, P. (1985) *Learning in Science: The Implications of Children's Science*, Auckland, Heinemann.

RESEARCH TRIANGLE INSTITUTE (1977) *National Survey of Science Education Curriculum Usage*, Research Triangle Park, North Carolina.

SCHAEFER, G. (1979) 'Concept formation in biology: the concept "growth"', *European Journal of Science Education*, 1, 1, pp 4–19.

SHULMAN, L.S. (1986) 'Paradigms and research programmes in the study of teaching: A contemporary perspective' in WITTROCK, M.C. (Ed) *Handbook of Research on Teaching*, 3rd edn, New York, Macmillan, pp 3–36.

SNIVELY, G. (1987) 'The use of a metaphor interview in the collection and analysis of interview data' in NOVAK, J. (Ed) *Proceedings of Second International Seminar, Misconceptions and Educational Strategies in Science and Mathematics*, Ithaca, Cornell University.

SUTTON, C.R. (1979) 'Language and curricular innovations, 33–36' in TAMIR, P. *et al.*, (Eds) *Curriculum Implementation and Its Relationship to Curriculum Development in Science*, Jerusalem, Israel Science Teaching Center.

TAMIR, P. *et al.* (1979) *Curriculum Implementation and Its Relationship to Curriculum Development in Science*, Proceedings of Bat-sheva conference, Jerusalem, Israel Science Teaching Centre.

WARING, M. (1979) *Social Pressures on Curriculum Innovations: A Study of the Nuffield Foundation Science Teaching Project*, London, Methuen.

WEST, L.H.T., FENSHAM, P.J. and GARRARD, J.E. (1985) 'Describing the cognitive structure of learners following instruction in chemistry, 29–50' in WEST, L.H.T. and PINES, A.L. (Eds) *Cognitive Structure and Conceptual Change*, New York, Academic Press.

WEST, L.H.T. and PINES, A.L. (1983) 'How "rational" is irrationality?', *Science Education*, 67, 1, pp 37–9.

WHITE, R.T. and TISHER, R.P. (1986) 'Research on natural sciences' in WITTROCK, M.C. (Ed) *Handbook of Research on Teaching*, 3rd edn, New York, Macmillan.

WILSON, B. (1981) *Cultural Contexts of Science and Mathematics Education: A Bibliographic Guide*, Leeds, Centre for Studies in Science Education, University of Leeds.

YOUNG, M.F.D. (1971) 'An approach to the study of curricula as socially organised knowledge' in YOUNG, M.F.D. (Ed) *Knowledge and Control*, London, Collier Macmillan.

ZOLLER, U. (1985) 'Interdisciplinary decision-making in the science curricula in the modern social context', in HARRISON, G. (Ed) *World Trends in Science and Technology Conference, Report on Second International Symposium*, Nottingham, Trent Polytechnic.

Familiar but Different: Some Dilemmas and New Directions in Science Education

Aikenhead, G. (1986) ‘Collective decision making in the social context of science’. Science Education, 69, 4, pp 453–475.

Andersson, B. (1987) Chemical Reactions, EKNA Report No. 12, Molndal, Institute for Pedagogy, Goteburgs University.

Apple, M.W. (1979) Ideology and the Curriculum, London, Routledge and Kegan Paul.

Bourdieu, P. and Passeron, J-C. (1977) Reproduction in Education, Society and Culture, London, Sage.

Brumby, M. (1981) ‘The use of problem solving in meaningful learning in biology’, Research in Science Education, 11, pp 103–110.

Brumby, M. (1984) Issues in Biology, Melbourne, Nelson.

Bybee, R. (1977) ‘The new transformation of science education’, Science Education, 61, 1, pp 85–97.

Champagne, A.B. , Gunstone, R.F. and Klopfer, L.E. (1985) ‘Effecting change in cognitive structures among physics students’ in West, L.H.T. and Pines, A.L. (Eds) Cognitive Structure and Conceptual Change, New York, Academic Press.

Comber, L.C. and Keeves, J.P. (1973) Science Education in Nineteen Countries, International Studies in Evaluation I, International Association for the Evaluation of Educational Achievement, New York, Wiley and Son.

CSSE (1978) Case Studies in Science Education. Urbana-Champaign, CIRCE and CCC, University of Illinois.

Fawns, R.A. (1987) The Maintenance and Transformation of School Science, PhD thesis, Clayton, Monash University.

Fensham, P.J. (1976) ‘Social contention in chemistry courses’, Chemistry in Britain, 12, 5, pp 148–151.

Fensham, P.J. (1983) ‘A research base for new objectives of science teaching’, Science Education, 67, 1, pp 3–12.

Fensham, P.J. (1984) ‘Conceptions, misconceptions, and alternative frameworks in chemical education’, Chemical Society Reviews, 13, 2, pp 199–217.

Fensham, P.J. (1986a) ‘Science for all’, Educational Leadership, 44, 4, pp 18–23.

Fensham, P.J. (1986b) ‘Lessons from science education in Thailand: A case study of gender and learning in the physical sciences’, Research in Science Education, 15, pp 92–100.

Gardner, P.L. (1971) Words in Science, Melbourne, Australian Science Education Project.

Gardner, P.L. (1975) ‘Attitudes to science: A review’, Studies in Science Education, 2, pp 1–41.

Gardner, P.L. , Lehrke, M. and Hoffman, L. (1985) Interests in Science and Technology Education, Kiel, IPN.

Gintis, H. (1972) ‘Towards a political economy of education’, Harvard Educational Review, 42, 2, pp 70–96.

Harding, J.M. (1983) Switched Off: The Science Education of Girls, York, Longmans for the Schools Council.

Harding, J.M. , Kelly, P.J. and Nicodemus, R.B. (1976) ‘The study of curriculum change’, Studies in Science Education, 3, pp 1–30.

Head, J. (1979) ‘Personality and the pursuit of science’, Studies in Science Education, 3.

Hegelson, S.L. , Blosser, P.E. and Howe, R.W. (1977) The Status of Pre-College Science, Mathematics and Social Science Education: 1955–1975, Vol.1, Science Education.

Hewson, P.W. (1981) ‘A conceptual change approach to learning science’, European Journal of Science Education, 3, pp 383–396.

Hodson, D. (1985) ‘Philosophy of science, science and science education’, Studies in Science Education, 12, pp 25–57.

Hurd, P. (1961) Biological Education in American Secondary Schools, 1890–1960, Colorado, Institute of Biological Science.

Jenkins, E. (1979) From Armstrong to Nuffield, London, Murray.

Kass, H. and Jenkins, F. (1986) ‘Normative perspectives on the nature of curricular knowledge in chemistry’, paper presented at annual meeting of National Association for Research in Science Teaching, San Francisco.

Layton, D. (1973) Science for the People, London, Allen and Unwin.

Lemke, J. (1982) Classroom Communication of Science, Report to N.S.F./RISE:SED R79–18961, (ERIC:ED222–346).

Marton, F. (1987) ‘Towards a pedagogy of contents’, Publication No. 4, Department of Education and Educational Research, Mölndal, University of Gothenburg.

Millar, R. (1988) ‘What is scientific method and can it be taught? in Wellington, J.J. (Ed) Skills and Processes in Science Education, London, Methuen.

Minssen, M. and Nentwig, P. (1983) Journal of Chemical Education, 60, pp 476–478.

National Science Foundation (1983) Educating Americans for the 21st Century, The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, Washington, DC, National Science Foundation.

Novak, J.D. (1981) ‘Effective science instruction: The achievement of shared meaning’, Australian Science Teachers Journal, 27, 1, pp 5–14.

Osborne, R. and Freyberg, P. (1985) Learning in Science: The Implications of Children's Science, Auckland, Heinemann.

Research Triangle Institute (1977) National Survey of Science Education Curriculum Usage, Research Triangle Park, North Carolina.

Schaefer, G. (1979) ‘Concept formation in biology: the concept “growth”’, European Journal of Science Education, 1, 1, pp 4–19.

Shulman, L.S. (1986) ‘Paradigms and research programmes in the study of teaching: A contemporary perspective’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan, pp 3–36.

Snively, G. (1987) ‘The use of a metaphor interview in the collection and analysis of interview data’ in Novak, J. (Ed) Proceedings of Second International Seminar, Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, Cornell University.

Sutton, C.R. (1979) ‘Language and curricular innovations, 33–36’ in Tamir, P. et al., (Eds) Curriculum Implementation and Its Relationship to Curriculum Development in Science, Jerusalem, Israel Science Teaching Center.

Tamir, P. et al. (1979) Curriculum Implementation and Its Relationship to Curriculum Development in Science, Proceedings of Bat-sheva conference, Jerusalem, Israel Science Teaching Centre.

Waring, M. (1979) Social Pressures on Curriculum Innovations: A Study of the Nuffield Foundation Science Teaching Project, London, Methuen.

West, L.H.T. , Fensham, P.J. and Garrard, J.E. (1985) ‘Describing the cognitive structure of learners following instruction in chemistry, 29–50’ in West, L.H.T. and Pines, A.L. (Eds) Cognitive Structure and Conceptual Change, New York, Academic Press.

West, L.H.T. and Pines, A.L. (1983) ‘How “rational” is irrationality?’, Science Education, 67, 1, pp 37–39.

White, R.T. and Tisher, R.P. (1986) ‘Research on natural sciences’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.

Wilson, B. (1981) Cultural Contexts of Science and Mathematics Education: A Bibliographic Guide, Leeds, Centre for Studies in Science Education, University of Leeds.

Young, M.F.D. (1971) ‘An approach to the study of curricula as socially organised knowledge’ in Young, M.F.D. (Ed) Knowledge and Control, London, Collier Macmillan.
Zoller, U. (1985) ‘Interdisciplinary decision-making in the science curricula in the modern social context’, in Harrison, G. (Ed) World Trends in Science and Technology Conference, Report on Second International Symposium, Nottingham, Trent Polytechnic.

Teachers in Science Education

Arzi, H.J. , White, R.T. and Fensham, R.J. (1987) Teachers’ knowledge of science: An account of a longitudinal study in progress’, paper presented at the annual meeting of the American Educational Research Association, Washington, D.C., April.
Baird, J.R. (1984) ‘Improving learning through enhanced metacognition’, unpublished PhD dissertation, Monash University.
Baird, J.R. (1986a) ‘Reflections on the nature of change’ in Baird, J.R. and Mitchell, I.J. (Eds) Improving the Quality of Teaching and Learning: An Australian Case Study — the PEEL project, Melbourne, Monash University Printery.
Baird, J.R. (1986b) ‘Improving learning through enhanced metacognition: A classroom study’, European Journal of Science Education, 8, 3, pp 263–282.
Baird, J.R. and Mitchell, I.J. (Eds) (1986) Improving the Quality of Teaching and Learning: An Australian Case Study — the PEEL project, Melbourne, Monash University Printery.
Barnes, D. (1976) From Communication to Curriculum, Middlesex , Penguin.
Biddle, B.J. and Anderson, D.S. (1986) Theory, methods, knowledge, and research on teaching’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Clark, C.M. and Peterson, P.L. (1986) Teachers’ thought processes’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Dunkin, M.J. and Biddle, B.J. (1974) The Study of Teaching, New York, Holt, Rinehart and Winston.
Easley, J.A. (1982) ‘Naturalistic case studies exploring social-cognitive mechanisms, and some methodological issues in research on problems of teachers, Journal of Research in Science Teaching, 19, 3, pp 191–203.
Elliott, J. (1976–77) ‘Developing hypotheses about classrooms from teachers’ practical constructs: An account of the work of the Ford Teaching Project’, Interchange, 7, 2, pp 2–22.
Erickson, F. (1986) ‘Qualitative methods in research on teaching’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Evertson, C.M. , Anderson, C.W. , Anderson, L.M. and Brophy, J.E. (1980) ‘Relationships between classroom behaviour and student outcomes in junior high mathematics and English classes’, American Educational Research Journal, 17, pp 43–60.
Fenstermacher, G.D. (1986) ‘Philosophy of research on teaching: Three aspects’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Fullan, M. (1985) ‘Integrating theory and practice’ in Hopkins, D. and Reid, K. (Eds) Rethinking Teacher Education, London, Croom Helm.
Fuller, F.F. (1969) ‘Concerns of teachers: A developmental conceptualisation’, American Educational Research Journal, 6, 2, pp 207–226.
Fuller, F.F. and Brown, O.H. (1975) ‘Becoming a teacher’ in Ryan, K. (Ed) Teacher Education, National Association for the Study of Education, 74th Yearbook, Part II, Chicago, IL, University of Chicago Press.
Gardner, P.L. , Gray, E.E. and Taylor, S.M. (1981) ‘Teacher transmission-interpretation and students’ attitudes to science’, Research in Science Education, 11, pp 171–179.
Kirkwood, V. , Carr, M. and Mc Chesney, J. (1986) ‘LISP (Energy) — Some preliminary findings’, Research in Science Education, 16, pp 175–183.
Olson, J.K. (1981) ‘Teacher influence in the classroom’, Instructional Science, 10, pp 259–275.
Osborne, R. and Biddulph, F. (1985) Learning in Science Project (Primary) Final Report, Hamilton, NZ, Science Education Research Unit, University of Waikato.
Power, C.N. and Tisher, R.P. (1973) ‘Teacher values and their association with teaching strategies in A.S.E.P. classes’, Science Education: Research, pp 51–60.
Schibeci, R.A. (1980) ‘Science teachers and science related attitudes, Research in Science Education, 10, pp 159–165.
Shavelson, R. (1983) ‘Review of research on teachers’ pedagogical judgements, plans and decisions’, Elementary School Journal, 83, 4, pp 392–413.
Shulman, L.S. (1986) ‘Paradigms and research programs in the study of teaching: A contemporary perspective’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Stake, R.E. and Easley, J.A. (1978) Case Studies in Science Education (2 vols.), Washington, D.C, US Government Printing Office.
Tisher, R.P. and Power, C.N. (1975) ‘A study of the effects of teaching strategies in A.S.E.P. classrooms’, Australian Journal of Education, 19, pp 127–145.
Weinstein, C.E. and Mayer, R.E. (1986) ‘The teaching of learning strategies’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
White, R.T. (1986) ‘Observations by a minor participant’ in Baird, J.R. and Mitchell, I.J. (Eds) Improving the Quality of Teaching and Learning: An Australian Case Study — the PEEL project, Melbourne, Monash University Printery.
White, R.T. and Tisher, R.P. (1986) ‘Research on natural sciences’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.
Wittrock, M.C. (1986) ‘Students’ thought processes’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan.

Learners in Science Education

Adey, P.S. (1987) ‘A response to “Towards a Lakatosian analysis of Piagetian and alternative conceptions research programs”', Science Education, 71, pp. 5–7.

Ameh, C.O. and Gunstone, R.F. (1986) ‘Science teachers’ concepts in Nigeria and Australia’, Research in Science Education, 16, pp. 73–81.

Arzi, H.J. , White, R.T. and Fensham, P.J. (1987) ‘Teachers’ knowledge of science: An account of a longitudinal study in progress’, paper presented at the annual meeting of the American Educational Research Association, Washington, DC, April.

Baird, J.R. and Mitchell I.J. (Eds.) (1986) Improving the Quality of Teaching and Learning: An Australian Case Study — the PEEL Project. Melbourne, Monash University Printery.

Brilliant, A. (1979) I May Not Be Totally Perfect, But Parts of Me Are Excellent, Santa Barbara, CA, Woodbridge Press.

Brumby, M.N. (1984) ‘Misconceptions about the concept of natural selection by medical biology students’, Science Education, 68, pp. 493–503.

Champagne, A.B. , Gunstone, R.F. and Klopfer, L.E. (1985) ‘Effecting changes in cognitive structures among physics students’ in West, L.H.T. and Pines, A.L. (Eds) Cognitive Structure and Conceptual Change, Orlando, FLA, Academic Press.

Champagne, A.B. and Klopfer, L.E. (1984) ‘Research in science education: The cognitive psychology perspective’ in Holdzkom, D. and Lutz, P.B. (Eds) Research Within Reach: Science Education. Charlestown, WV, Appalachia Educational Laboratory.

Champagne, A.B. , Klopfer, L.E. and Anderson, J.H. (1980) ‘Factors influencing the learning of classical mechanics’, American Journal of Physics, 48, pp. 1074–1079.

Driver, R. (1983) The Pupil as Scientist? Milton Keynes, Open University Press.

Driver, R. and Bell, B. (1986) ‘Students’ thinking and the learning of science: A constructivist view’, School Science Review, 67, 240, pp. 443–456.

Driver, R. and Erickson, G. (1983) Theorics-in-action: Some theoretical and empirical issues in the study of students’ conceptual frameworks in science’, Studies in Science Education, 10, pp. 37–60.

Driver, R. , Guesne, E. and Tiberghien, A. (Eds) (1985) Children's Ideas in Science, Milton Keynes, Open University Press.

Duit, R. , Jung, W. and Von Rhöneck, C. (Eds) (1985) Aspects of Understanding Electricity: Proceedings of an International Workshop, Keil, West Germany, Vertrieb, Schmidt & Klaunig.

Engel Clough, E. and Driver, R. (1986) ‘ A study of consistency in the use of students’ conceptual frameworks across different task contexts’, Science Education, 70, pp. 473–496.

Erickson, G.L. (1984) ‘Some issues on cognitive structure and cognitive change in science education: One perspective from North America’, paper presented at the annual meeting of the American Educational Research Association, New Orleans, April.

Fensham, P.J. (1983) ‘A research base for new objectives of science teaching’, Science Education, 67, pp. 3–12.

Gauld, C. (1987) ‘Student beliefs and cognitive structure’, Research in Science Education, 17 (in press).

Gilbert, J.K. and Watts, D.M. (1983) ‘Concepts, misconceptions and alternative conceptions: Changing perspectives in science education’, Studies in Science Education, 10, pp. 61–98.

Good, R.G. (1977) How Children Learn Science, New York, Macmillan.

Groen, G.J. (1978) ‘The theoretical ideas of Piaget and educational practice’ in Suppes, P. (Ed) Impact of Research on Education: Some Case Studies (Summaries). Washington, National Academy of Education.

Gruber, H.E. and Vonèche, J.J. (Eds) (1982) The Essential Piaget, London, Routledge & Kegan Paul.

Gunstone, R.F. (1987) ‘Student understanding in mechanics: A large population survey, American Journal of Physics, 55, pp. 691–696.

Gunstone, R.F. and Champagne, A.B. (in press) ‘Promoting conceptual change in the laboratory’ in Hegarty-Hazel, E. (Ed) The Science Curriculum and the Student Laboratory, London, Croom Helm.

Gunstone, R.F. , Champagne, A.B. and Klopfer, L.E. (1981) ‘Instruction for understanding: A case study’, Australian Science Teachers Journal, 27, 3, pp. 27–32.

Gunstone, R.F. and White, R.T. (1981) ‘Understanding of gravity’, Science Education, 65, pp. 291–299.

Gunstone, R.F. , White, R.T. and Fensham, P.J. (1988) ‘Developments in style and purpose of research on the learning of science’, Journal of Research in Science Teaching (in press).

Head, J. (1982) ‘What can psychology contribute to science education?’, School Science Review, 63, pp. 631–642.

Helm, H. and Novak, J.D. (Eds) (1983) Proceedings of the International Seminar on Misconceptions in Science and Mathematics, Ithaca, NY, Cornell University.

Hewson, P.W. (1981) ‘A conceptual change approach to learning science’, European Journal of Science Education, 3, pp. 383–396.

Lawson, A.E. (1982) ‘The reality of general cognitive operations’, Science Education, 66, pp. 229–241.

Lawson, A.E. (1985) ‘A review of research on formal reasoning and science teaching’, Journal of Research in Science Teaching, 22, pp. 569–617.

Linn, M.C. (1986) ‘Science’ in Dillon, R. and Sternberg, R.J. (Eds) Cognition and Instruction, Orlando, FLA, Academic Press.

Linn, M.C. (1987) ‘Establishing a research base for science education: Challenges, trends, and recommendations’, Journal of Research in Science Teaching, 24, pp. 191–216.

Macnamara, J. (1982) Names for Things: A Study of Human Learning, Cambridge, MA, Massachusetts Institute of Technology Press.

Mc Closkey, M. (1983) ‘Intuitive physics’, Scientific American, 248, pp. 114–122.

Mc Dermott, L.C. (1984) ‘Research on conceptual understanding in mechanics’, Physics Today, July, 37, 7, pp. 24–32.

Magoon, A.J. (1977) ‘Constructivist approaches in educational research’, Review of Educational Research, 47, pp. 651–693.

Nixon, M. (1978) ‘The nature of the learner: A point of view and implications for curricula’, Australian Science Teachers Journal, 24, 3, pp. 15–22.

Novak, J.D. (1978) ‘An alternative for Piagetian psychology for science and mathematics education’, Studies in Science Education, 5, 1–30.

Novak, J.D. and Gowin, D.B. (1984) Learning How to Learn, Cambridge, MA, Cambridge University Press.

Nussbaumn, J. and Novick, S. (1982) ‘Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy’, Instructional Science, 11, pp. 183–200.

Osborne, R. and Freyberg, P. (Eds) (1985) Learning in Science: The Implications of Children's Science, Auckland, Heinemann.

Osborne, R.J. and Wittrock, M.C. (1983) ‘Learning science: A generative process’, Science Education, 67, pp. 489–508.
Osborne, R.J. and Wittrock, M.C. (1985) ‘The generative learning model and its implications for science education’, Studies in Science Education, 12, pp. 59–87.
Piaget, J. (1929) The Child's Conception of the World, London, Routledge & Kegan Paul.
Pines, A.L. and West, L.H.T. (1986) ‘Conceptual understanding and science learning: An interpretation of research within a sources-of-knowledgc framework’, Science Education, 70, pp. 583–604.
Research on Physics Education: Proceedings of the First International Workshop . (1984) Paris: LaLonde les Maures, Editions du CNRS.
Rumelhart, D.E. and Norman, D.A. (1978) ‘Accretion, tuning and restructuring: Three modes of learning’, in Klatzky, R.L. and Cotton, J.W. (Eds) Semantic Factors in Cognition, Hillsdale, NJ, Lawrence Erlbaum.
Shayer, M. and Adey, P. (1981) Towards a Science of Science Teaching, London, Heinemann.
Shuell, T.J. (1986) ‘Cognitive conceptions of learning’, Review of Educational Research, 56, pp. 411–436.
Stenhouse, D. (1986) ‘Conceptual change in science education: Paradigms and language games’, Science Education, 70, pp. 413–425.
Tasker, R. (1981) ‘Children's views and classroom experience’, Australian Science Teachers Journal, 27, 3, pp. 33–37.
Vosniadou, S. and Brewer, W.F. (1987) ‘Theories of knowledge restructuring in development’, Review of Educational Research, 57, pp. 51–67.
West, L.H.T. and Pines, A.L. (Eds) (1985) Cognitive Structure and Conceptual Change. Orlando, FLA, Academic Press.
White, R.T. and Tisher, R.P. (1986) ‘Research on natural sciences’ in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd edn, New York, Macmillan, pp. 874–905.

What Children Bring to Light: Towards Understanding What the Primary School Science Learner Is Trying to Do

Andersson, B. and Karrqvist, C. (1982) Ljuset och dess engenskaper, EKNA-projecektet, Institutionen for praktisk pedagogik, Molndal, Sverige, 1981. Light and Its Properties, translated into English by Gillian Thylander.
Anderson, C. and Smith, E. (1983) ‘Children's preconceptions and content area in textbooks’ in Duffy, G. , Roehler, L. and Mason, J. (Eds) Comprehension Instruction: Perspectives and Suggestions, New York, Longman, Inc.
Apelman, M. , Colton, R. , Flexer, A. and Hawkins, D. (1983) A Report on Critical Barriers to the Learning and Understanding of Elementary Science, Boulder, CO, National Science Foundation Contract #SED 80–08581, Mountain View Center.
Asimov, I. (1984) ‘Science and beauty’ in Gardner, M. (Ed) The Sacred Beetle and Other Great Essays in Science, Oxford, Oxford University Press.
Brophy, J. (1982) ‘Schooling as students experience it’, The Elementary School Journal, 82, 5, pp. 519–529.
Driver, R. and Oldham, V. (1985) ‘A constructivist approach to curriculum development in science’, paper presented to the symposium, ‘Personal Construction of Meaning in Educational Settings’, at the annual meeting of the British Educational Research Association, Sheffield, August.
Freyberg, P. and Osborne, R. (1985) ‘Assumptions about teaching and learning’ in Osborne, R. and Freyberg, P. (Eds) Learning in Science: The Implications of Children's Science, Portsmouth, NH, Heinemann.
Fynn , (1974) Mr. God This Is Anna, London, William Collins and Sons, Ltd.
Guesne, E. (1988) ‘Childrens’ Ideas about Light’, to be published in New Trends Physics Teaching, IV, Paris, Unesco Publications.
Jung, W. (1981) ‘Conceptual frameworks in elementary optics’, working paper presented at the Conference in Ludwigsburg, Johann Wolfgang Goethe-Universitat Institut für Didaktik der Physik, Grafstrasse 39, 6000 Frankfurt a.M. 90, 14–16 September.
Kelly, G. (1955) The Psychology of Personal Constructs (Vols. 1 and 2), New York, W.W. Norton and Company.
Magoon, A. (1977) ‘Constructivist approaches in educational research’, Review of Research in Education, 47, 4, pp. 651–693.
Navarra, J. (1955) The Development of Scientific Concepts in a Young Child: A Case Study, Westport, CT, Greenwood Press.
Nyberg, D. (1971) Tough and Tender Learning, Palo Alto, CA, National Press Books.
Pope, M. and Gilbert, J. (1983) ‘Personal experience and the construction of knowledge in science’, Science Education, 67, 2, pp. 193–203.
Posner, G. , Strike, K. , Hewson, P. and Gertzog, W. (1982) ‘Accommodation of a scientific conception: Toward a theory of conceptual change’, Science Education, 66, 2, pp. 211–227.
Shapiro, B. (1987) ‘What children bring to light: Conversations with grade 5 children during their study of the topic light’, unpublished doctoral dissertation, University of Alberta, Edmonton.
Smith, F. (1973) ‘Twelve easy ways to make learning to read difficult and one difficult way to make it easy’ in Smith, F. (Ed), Psycholinguistics and Reading, Toronto, Holt, Rinehart and Winston.
Stead, B. and Osborne, R. (1980) ‘Exploring students’ concepts of light’, The Australian Science Teachers Journal, 26, 3, pp. 84–90.
Watzlawick, P. (1984) Invented Reality, New York, Norton.
Whitman, W. (1965) Leaves of Grass, New York, New York University Press.

Theory into Practice I

Ausubel, D.P. (1968) Educational Psychology: A Cognitive View, New York, Holt, Rinehart & Winston.
Baird, J.R. (1984) Improving Learning Through Enhanced Metacognition, PhD thesis, Monash University Printery.
Baird, J.R. (1986) ‘Improving learning through enhanced metacognition: A classroom study’, European Journal of Science Education, 8, pp. 263–282.
Baird, J.R. and Mitchell, I.J. (Eds) (1986) Improving the Quality of Teaching and Learning: An Australian Case Study — The PEEL project, Melbourne, Monash University Printery.

Baird, J.R. and White, R.T. (1982a) ‘A case study of learning styles in biology’, European Journal of Science Education, 4, pp. 325–337.
Baird, J.R. and White, R.T. (1982b) ‘Promoting self-control of learning’, Instructional Science, 11, pp. 227–247.
Baird, J.R. and White, R.T. (1984) ‘Improving learning through enhanced metacognition: A classroom study’, paper presented at the annual meeting of the American Educational Research Association, New Orleans, April.
Bloom, B.S. (1968) ‘Learning for mastery’, Evaluation Comment, Los Angeles, Center for the Study of Evaluation of Instructional Programs, UCLA.
Brown, A.L. (1978) ‘Knowing when, where, and how to remember: A problem of metacognition’ in Glaser, R. (Ed) Advances in Instructional Psychology: Vol. 1, Hillsdale, NJ, Erlbaum.
Brumby, M.N. (1984) ‘Misconceptions about the concept of natural selection’, Science Education, 68, pp. 493–502.
Campbrll, D.T. and Stanley, J.C. (1963) ‘Experimental and quasi-experimental designs for research on teaching’ in Gage, N.L. (Ed) Handbook of Research on Teaching, Chicago, IL, Rand McNally.
Carroll, J.B. (1963) ‘A model of school learning’, Teachers College Record, 64, pp. 723–733.
Castle, E.B. (1961) Ancient Education and Today, Harmondsworth, Penguin.
Fensham, P.J. (1984) ‘Conceptions, misconceptions, and alternative frameworks in chemical education’, Chemical Society Reviews, 13, 2, pp. 199–217.
Favell, J.H. (1976) ‘Metacognitive aspects of problem solving’ in Resnick, L.B. (Ed) The Nature of Intelligence, Hillsdale, NJ, Erlbaum.
Gagné, R.M. (1962) ‘The acquisition of knowledge’, Psychological Review, 69, pp. 355–365.
Gagné, R.M. and White, R.T. (1978) ‘Memory structures and learning outcomes’, Review of Educational Research, 48, pp. 187–222.
Gunstone, R.F. , Champagne, A.B. , and Kliofer, L.E. (1981) ‘Instruction for understanding: A case study’, Australian Science Teachers Journal, 27, 3, pp. 27–32.
Gunstone, R.F. and White, R.T. (1981) ‘Understanding of gravity’, Science Education, 65, pp. 291–299.
West, L.H.T. and Fensham, P.J. (1976) ‘Prior knowledge or advance organizers as effective variables in chemical learning’, Journal of Research in Science Teaching, 13, pp. 297–306.
White, R.T. (1973) ‘A limit to the application of learning hierarchies’. Australian Journal of Education, 17, pp. 153–156.
White, R.T. (1974) ‘The validation of a learning hierarchy’, American Educational Research Journal, 11, pp. 121–136.
White, R.T. (1985) ‘The importance of context in educational research’, Research in Science Education, 15, pp. 92–102.
White, R.T. and Tisher, R.P. (1986) ‘Research on natural sciences’, in Wittrock, M.C. (Ed) Handbook of Research on Teaching, 3rd ed, New York, Macmillan.
Wittrock, M.C. (1974) ‘Learning as a generative process’, Educational Psychologist, 11, pp. 87–95.

Theory into Practice II: A Constructivist Approach to Curriculum Development

Anderson, R.C. (1984) ‘Some reflections on the acquisition of knowledge’, Educational Researcher, 13, 9, pp 5–10.
Baird, J.R. and Mitchell, I. J. (Eds) (1986) Improving the Quality of Teaching and Learning: An Australian Case Study — the PEEL project, Melbourne, Monash University Printery.
Bell, B.F. and Brook, A. (1985) The Construction of Meaning and Conceptual Change in Classroom Settings: Case Studies in Plant Nutrition, Leeds, Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education, University of Leeds.
Bereiter, C. (1985) ‘Toward a solution of the learning paradox’, Review of Educational Research, 55, 2, pp 201–226.
Bishop, A. (1985) ‘The social construction of meaning — a significant development for mathematics education’, For the Learning of Mathematics, 5, 1, pp 24–28.
Brook, A. (1987) ‘Designing experiences to take account of the development of children's ideas: An example from the teaching and learning of energy’, paper presented at the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Cornell University, July.
Brook, A. and Drivere, R. (1986) The Construction of Meaning and Conceptual Change in Classroom Settings: Case Studies in the Learning of Energy, Leeds, Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education, University of Leeds.
Brown, D.E. and Clement, J. (1987) ‘Overcoming misconceptions in mechanics: A comparison of two example-based teaching strategies’, paper presented at the annual meeting of the American Educational Research Association, Washington, DC, April.
Carey, S. (1985) Conceptual Change in Childhood, Cambridge, Mass., MIT Press.
Children's Learning in Science (1987) CLIS in the Classroom: Approaches to Teaching, Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds.
Collins, H.M. (1985) Changing Order, New York, Sage Publications.
Driver, R. and Bell, B. (1986) ‘Students’ thinking and the learning of science: A constructivist view’, School Science Review, 67, pp 443–456.
Driver, R. and Oldham, V. (1986) ‘A constructivist approach to curriculum development in science’, Studies in Science Education, 13, pp 105–122.
Edwards, D. and Mercer, N. (1987) Common Knowledge, London, Methuen.
Glaserfeld, Von E. (1983) ‘Learning as a constructive activity’ in Bergeron, J.C. and Herscovis, N. (Eds) Proceedings of the Fifth Annual Meeting PME-NA, Montreal, PME-NA.
Greeno, J.G. (1978) ‘A study of problem solving’ in Glaser, R. (Ed) Advances in Instructional Psychology, Hillsdale, NJ, Lawrence Erlbaum Associates.
Guesne, E. (1985) ‘Light’ in Driver, R. , Guesne, E. and Tiberghien, A. (Eds) Children's Ideas in Science, Milton Keynes, Open University Press.
Head, J. (1985) The Personal Response to Science, Cambridge, Cambridge University Press.
Johnson-Laird, P.N. (1983) Mental Models, Cambridge, Cambridge University Press.
Larkin, J.H. (1983) ‘The role of problem representation in physics’ in Gentner, D. and Stevens, A. (Eds) Mental Models, Hillsdale, NJ, Lawrence Erlbaum Associates.

Newell, A. and Simon, H.A. (1972) Human Problem Solving, Englcwood Cliffs, NJ, Prentice Hall.
Posner, G. (1982) ‘A cognitive science conception of curriculum and instruction’, Journal of Curriculum Studies, 14, 4, pp 343–351.
Rumelhart, D.E. and Norman, D.A. (1981) ‘Accretion, tuning and restructuring: Three modes of learning’ in Klatzky, R.L. and Cotton, J.W. (Eds) Semantic Factors in Cognition, Hillsdale, NJ, Lawrence Erlbaum Associates.
Schank, R.C. and Abelson, R.P. (1977) Scripts, Plans, Goals and Understanding. An Inquiry into Human Knowledge Structures, Hillsdale, NJ, Lawrence Erlbaum Associates.
Scott, P. (1987) ‘The process of conceptual change in science: A case study of the development of a secondary pupil's ideas relating to matter’, paper presented at the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Cornell University, July.
Scott, P. and Wightman, T. (1985) Teaching the particulate theory of matter — a constructivist approach’, paper presented at the annual meeting of the British Educational Research Association Meeting, Sheffield, August.
Strauss, S. (1981) ‘Cognitive development in school and out’, Cognition, 10, 295–300.
Strauss, S. (Ed) with Stavy, R. (1982) U-shaped Behavioural Growth,New York, Academic Press.
Wightman, T. et al. (1986) The Construction of Meaning and Conceptual Change in Classroom Settings: Case Studies in the Particulate Theory of Matter, Leeds, Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education, University of Leeds.

Role of Language in Science Education

Barnes, D. (1986) ‘Language in the secondary classroom’ in Barnes, D. , Britton, J. and Torbe, M. (Eds) Language the Learner and the School, 3rd edn, Harmondsworth, Penguin, pp 11–87.
Bloom, L. (Ed) (1978) Readings in Language Development, New York, John Wiley and Sons.
Fowler, R. , Hodge, B. , Kress, G. and Trew, T. (1979) Language and Control, London, Routledge & Kegan Paul.
Gardner, P.L. (1974) ‘Language difficulties of science students’, The Australian Science Teachers’ Journal, 20, 1, pp 63–76.
Gardner, P.L. (1980) ‘Difficulties with non-technical scientific vocabulary amongst secondary school students in the Philippines’, The Australian Science Teachers’ Journal, 26, 2, pp 82–90.
Harrison, P. (1983) Inside the Inner City, Harmondsworth, Penguin, pp 277–298.
Jensen, A.R. (1969) ‘How much can we boost IQ and scholastic achievement?’, Harvard Educational Review, 39, 1, pp 1–123.
Kulkarni, M.S. and Kumar, A. (1986) ‘A mathematical model of progressive literacy’, Journal of Mathematical Society, 12, 3, pp 275–298.
Kulkarni, M.S. and Kumar, A. (1988) ‘Interactive Markovian models of progressive trends’, Journal of Mathematical Sociology.
Kulkarni, V.G. (1984) ‘Designing and testing the effectiveness of remedial measures to improve the scholastic achievement of students coming from socio-economically deprived class’, 3rd International Symposium on World Trends in Science and Technology Education, pp 144–148.
Kulkarni, V.G. (1985) ‘Alternatives in education’, Man and Development, March, pp 35–58.
Kulkarni, V.G. (1987) ‘Role of language in science education’, Journal of Education and Social Change, 1, June, pp 113–131.
Kulkarni, V.G. and Agarkar, S.C. (1985) Talent Search and Nurture among the Underpriviledged, Bombay, Homi Bhabha Centre for Science Education.
Kulkarni, V.G. and Gambhir, V.G. (1981) ‘The effect of language barrier on science education’, Indian Educational Review, 16, pp 48–58.
Kulkarni, V.G. , Ramadas, J. , Ozarkar, S.P. , Bhat, N.R. and Gambhir, V.G. (1988) Non-formal Science-Based Education, Bombay, Homi Bhabha Centre for Science Education.
Olson, D.R. (1986) ‘The cognitive consequences of literacy’, Canadian Psychology, 27, 2, pp 109–121.
Scribner, S. and Cole, M. (1973) Cognitive consequences of formal and informal education’, Science, 182, pp 553–559.
Scribner, S. and Cole, M. (1981) The Psychology of Literacy, Cambridge, MA, Harvard University Press.
Shaughnessy, M.P. (1977) Errors and Expectations, New York, Oxford University Press.
Ward, C. (1974) The Child in the City, Harmondsworth, Penguin.
Werner, D. (1978) Where There Is No Doctor, New York, Macmillan.
Whorf, B.L. (1956) Language Thought and Reality, Cambridge, MA, MIT Press.
World Development Report (1987) Oxford, Oxford University Press (for the World Bank), pp 262–263.
Zigler, E. and Valentine, J. (Eds) (1979) Operation Head Start, New York, The Free Press, pp 399–514.

Practical Work and Science Education I

Ausubel, D.P. (1965) ‘An evaluation of conceptual scheme approach to science curriculum development’, Journal of Research in Science Teaching, 2, pp 255–264.
Beaty, T.W. and Woolnough, B.E. (1982) ‘Why do practical work in 11–13 science?’ School Science Review, 63, 225, pp 768–770.
Ben-Zvi, R. , Hofstein, A. , and Kempa, R.F. (1977) ‘Mode of instruction in high school chemistry’, Journal of Research in Science Teaching, 14, 5, pp 433–439.
Comber, L.C. and Keeves, T.P. (1973) Science Education in Nineteen Countries: IEA International Study in Evaluation I, Upsala, Almquist and Wiksel Informationindustri.
Denny, M. and Chennell, F. (1986) ‘Science practicals: What do pupils think’, European Journal of Science Education. 8, 3, pp 325–326.
Department of Education and Science (1982) Assessment of Performance Unit (APU), Report No. 1, London, HMSO.
Dewey, J. (1951) Experience and Education, New York, Macmillan.
Eglen, J.R. and Kempa, R.F. (1974) ‘Assessing manipulative skills in practical chemistry’, School Science Review, 56, 195, p 261.

Fensham, P.J. (1980) ‘Constraint and autonomy in Australian secondary science education’, Journal of Curriculum Studies, 12, 3, pp 189–206.
Fensham, P.J. (1981) ‘Heads, hearts and hands — Future alternatives for science education’, Australian Science Teachers Journal, 27, 1, pp 53–60.
Fensham, P.J. , (1984a) ‘Nyholm lecture: Conception misconception and alternative framework in chemical education’, Chemical Society Review, 13, 2, p 199–217.
Fensham, P.J. , (1984b) ‘Current research in chemical education’ in Waddington, D.J. (Ed). Teaching School Chemistry, UNESCO, Paris.
Gagnè, R.M. and White, R.T. (1978) ‘Memory structure and learning outcomes’, Educational Research, 48, 2, pp 187–222.
Hearle, R. (1974) paper presented at the National Association for Research in Science Teaching (NARST), Chicago.
Hodson, D. (1985) ‘Philosophy of science, science and science education’, Studies in Science Education, 12, pp 25–51.
Hofstein, A. , Ben-Zvi, R. Samu, L.D. and Kempa, R.F. (1976) ‘The effectiveness of film experiment in high school chemical education’, Journal of Chemical Education, 53, pp 518–520.
Hofstein, A. and Giddings, G. (1980) Trends in Assessment of Laboratory Performance in High School Science Instruction, Technical Report 20, Iowa, University of Iowa.
Hofstein, A. and Lunetta, V.N. (1982) The role of laboratory in science teaching: Neglected aspects of research’, Review of Educational Research, 52, 2, pp 201–217.
IPST (1977) The Institute for the Promotion of Teaching Science and Technology of Thailand, Bangkok, UNESCO.
Jenkins, E.W. and Whitfield, R. (1974) Readings in Science Education: A Source Book, Science Teacher Education Project, Maidenhead, McGraw-Hill Books.
Johnstone, A.H. and Wham, A.J.B. (1982) The demand of practical work’, Education in Chemistry, 19, 3, pp 71–73.
Kempa, R.F. (1986) Assessment in Science,Cambridge, Cambridge University Press.
Kempa, R.F. and Ward, J.E. (1975) The effects of different modes of task orientation on observational attainment in practical chemistry’, Journal of Research in Science Teaching, 12, pp 69–76.
Kerr, J.F. (1963) *Practical Work in School Science*, Leicester, Leicester University Press.
Klainin, S. (1984) ‘Activity-based learning in chemistry’, PhD thesis, Melborne, Monash University.
Klainin, S. and Fensham P.J. (1987) International Journal of Science Education, 9, 2, pp 217–227.
Klainin, S. , Fensham, P.J. , and West, L.H.T. , (1988) The superior achievement of girls in physics and chemistry in upper secondary schools in Thailand’, Research in Science and Technological Education, in press.
Klopfer, L.E. (1971) ‘Evaluation for learning is science’ in Bloom, B.S. , Hasting, J.T. and Madaus, G.F. Handbook of Formative and Summative Evaluation of Student Learning, New York, McGraw-Hill.
Kojima, S. (1974) ‘LEA science study in Japan with reference to practical work’, Comparative Education Review, 18, pp 26–276.
Kreiger, A.G. (1982) Journal of Chemical Education, 59, 3, pp 230–231.
Kruglak, H. (1955) American Journal of Physics, 23, pp 82–87.
Lynch, P. and Ndyetabura, V. (1984) ‘Students’ attitudes to school practical work in Tasmanian schools’, Australian Science Teachers Journal, 29, 2, pp 25–29.
Mathews, J.C. (1984) ‘Assessment of students’ in Waddington, D.J. (Ed) Teaching School Chemistry, Paris, UNESCO, pp 223–274.
Michels, W.C. (1962) ‘The role of experimental work’, American Journal of Physics, 30, pp 172–178.
Ramsey, G.A. (1975) ‘Science as an instructional system’, in Gardner, P.L. (Ed) The Structure of Science Education, Hawthorn, Longman.
Ratnaike , (1987) personal communication.
Rousseau, J.J. (1950) Emile, Everyman Library, London, Dent.
Rutherford, J. and Gardner, M.H. (1970) ‘Integrated Science Teaching’, in UNESCO New Trends in Integrated Science Teaching, Vol 1, Paris, UNESCO, pp 47–56.
Schwab, J.J. (1962) The Teaching of Science as Enquiry, Cambridge, MA, Harvard University Press.
Suan, M.Z. (1976) ‘An evaluation of A.S.E.P. — A case study approach’, MEd thesis, Melbourne, Monash University.
Tamir, P. (1984) ‘Teaching and learning in high school biology classes in Israel’, paper presented at the Australian Science Education Research Conference, Melbourne, Australia.
Tan, Y.L. (1980) ‘Toward achieving the central objective of school practical work’, Journal of the Association of Science and Mathematics Education (Penang), 2, 1.
Tunnicliffe, S.D. (1981) ‘What is science?’ School Science Review, 62, 220, pp 548–550.
UNESCO (1982) A Report of Regional Design Workshop on Chemistry Curriculum and Teaching Materials in Asia, Bangkok, UNESCO.
White, R.T. (1979) ‘Relevance of practical work to comprehension of physics’, Physics Education, 14, pp 384–387.

Practical Work and Science Education II

Ausubel, D.P. (1968) Educational Psychology,New York, Holt, Rinchart and Winston.
Barnes, L.W. (1967) ‘The development of a student checklist to determine laboratory practices in his high school biology’ in Lee, A.E. (Ed) Research and Curriculum Development in Science Education, Vol. 1. Austin, TX, University of Texas.
Bates, G.R. (1978) ’The role of the laboratory in secondary school science programs’ in Rowe, M.B. (Ed) What Research Says to the Science Teacher, 1, pp 55–82.
Belanger, M. (1971) ‘Learning studies in science education’, Review of Educational Research, 39, pp 371–395.
Beasley, W.F. (1978) ‘Laboratory psychomotor skill development using physical and mental practice strategies’, Research in Science Education, 8, pp 135–144.
Ben-Zvi, R. et al. (1976a) ‘The effectiveness of filmed experiments in high school chemical education’, Journal of Chemical Education, 53, pp 575–577.
Ben-Zvi, R. et al. (1976b) ‘The attitude of high school students to the use of filmed experiments in laboratory instruction’, Journal of Chemical Education, 14, pp 575–577.

Ben-Zvi, R. et al (1977) ‘Modes of instruction in high school chemistry’, Journal of Research in Science Teaching, 14, pp 433–439.

Blosser, P.E. (1981) A Critical Review of the Role of the Laboratory in Science Teaching, Science Education Information Report. Columbus, OH Center for Science and Mathematics Education, Ohio State University.

Bryce, T.G.K. and Robertson, I.J. (1985) ‘What can they do? A review of practical assessment in science’, Studies in Science Education, 12, pp 1–24.

Bybee, R.W. (1970) ‘The effectiveness of an individualized approach to general education earth science laboratory’, Science Education, 54, pp 157–161.

Charen, G. (1966) ‘Laboratory method build attitudes’, Science Education, 50, pp 54–57.

Cohen, I. (1987) ‘Various strategies for the teaching of the topics chemical energy and chemical equilibrium: Development, implementation and evaluation’, unpublished PhD dissertation. Rehovot, The Weizmann Institute of Science.

Coulter, J.C. (1966) ‘The effectiveness of inductive laboratory demonstration and deductive laboratory in biology’, Journal of Research in Science Teaching, 4, pp 185–186.

Doran, R. (1978) ‘Assessing the outcomes of science laboratory activities’, Science Education, 62, 3, pp 401–409.

Dreyfus, A. (1986) ‘Manipulating and diversifying the levels of difficulty and task sophistication of one and the same laboratory exercise’, European Journal of Science Education, 8, 1, pp 17–26.

Eggleston, J.F. et al. (1976) Process and Product of Science Teaching,London, Macmillan Education.

Eglen, J.R. and Kempa, R.F. (1974) ‘Assessing manipulative skills in practical chemistry’, School Science Review, 56, pp 737–740.

Fix, W.T. and Renner, J.W. (1979) ‘Chemistry and experiments in the secondary school’, Journal of Chemical Education, 56, pp 737–740.

Frazer, B.J. (1981) ‘Learning environment in curriculum education’, Evaluation in Education: An International Review Series, 5, pp 3–93.

Fuhrman, M. et al. (1978) The Laboratory Structure and Task Analysis Inventory (LA.I.): A User Handbook,Iowa City, IO, University of Iowa, Technical Report No. 14.

Ganiel, U. and Hofstein, A. (1982) ‘Objective and continuous assessment of student performance in the physics laboratory’, Science Education, 66, 4, pp 581–591.

Gardner, M. (1979) ‘Trends in the development and implementation of science curriculum in the U.S.A.’ in Tamir, P. et al.(Eds) Curriculum Implementation and Its Relationship to Curriculum Development,Jerusalem, Israel Science Teaching Center, pp 271–276.

Golman, M. (1975) ‘Assessing laboratory instruction in biology’, Iowa Science Teacher Journal, 19, pp 4–10.

Grobman, H. (1970) Developmental Curriculum Projects: Decision, Points and Process,Itasca, IL, Peacock Publishers.

Gutman, H.F. (1940) ‘The life of Ira Remsen’, Journal of Chemical Education, 17.

Herron, M.D. (1971) ‘The nature of scientific inquiry’, School Review, 79, pp 171–212.

Hill, B.W. (1976) ‘Using college chemistry to influence creativity’, Journal of Research in Science Teaching, 13, pp 71–77.

Hineksman, N.O. (1973) ‘The function of the school laboratory’, The Australian Science Teacher Journal, 19, pp 81–86.

Hofstein, A. et al. (1976) ‘The measurement of interest in and attitude to laboratory work amongst Israeli high school students’, Science Education, 60, pp 401–411.

Hofstein, A. and Lunetta, V.N. (1982) ‘The role of the laboratory in science teaching’, Review of Educational Research, 52, 2, pp 201–217.

Hurd, P.D. (1969) New Directions in Teaching Secondary School Science.Chicago, IL, Rand McNally.

Jeffrey, J. (1967) ‘Identification of objectives of the chemistry laboratory and development of means for measuring students achievement of some of these objectives’, unpublished PhD dissertation, Texas, University of Texas.

JOINT MATRICULATION BOARD (1979) ‘The internal assessment of practical skills in chemistry (advanced) — Suggestions for practical work and advice on sources of information’, Universities of Manchester, Liverpool, Leeds, Sheffield and Birmingham, January.

Johnson, R.T. et al. (1974) ‘Inquiry and the development of positive attitudes’, Science Education, 58, pp 51—56.

Johnsone, A.H. and Wham, A.J.B. (1982) ‘The demands of practical work’, Education in Chemistry,May, pp 71–73.

Karplus, R. (1977) ‘Science teaching and the development of reasoning’, Journal of Research in Science Teaching, 14, pp 169–175.

Kelly, P.J. and Lister, R.F. (1969) ‘Assessing practical ability in Nuffield ‘A level biology’ in Eggleston, J.F. et al.(Eds) Studies in Assessment,London, English University Press, pp 121–152.

Kempa, R.F. (1986) Assessment in Science,Cambridge, Cambridge Science Education Series, Cambridge University.

Kempa, R.F. and Ward, J.E. (1975) ‘The effect of different modes of task orientation on observational attainment in practical chemistry’, Journal of Research in Science Teaching, 12, pp 69–76.

Kolesnick, W.B. (1978) ‘Motivation’, Understanding and Influencing Human Behaviour, Boston, MA, Allyn and Beacon.

Lunetta, V.N. (1974) ‘Computer-based dialogues: A supplement to the physics curriculum’, The Physics Teacher, 12, pp 355–356.

Lunetta, V.N. and Hofstein, A. (1980) ‘The science lab: A new look at goals and practice’, unpublished manuscript, Iowa City, University of Iowa.

Lunetta, V.N. and Tamir, P. (1979) ‘Matching lab. activities with teaching goals’, The Science Teacher, 46, pp 22–24.

Milner, N. et al. (1987) ‘Variables that affect students’ enrolment in science courses’, Research in Science and Technological Education.

Newman, B.E. (n.d.) ‘Practical work in secondary school chemistry’, unpublished report, University of New South Wales, School of Education, pp 1–7.

Ogborn, J. (1978) ‘Aims and organization of laboratory work’ in Jones, J.G. and Lewis, J.L. (Eds) The Role of the Laboratory in Physics Education,Birmingham, John Goodman and Sons (printers) Limited, pp 1–64.

Oekebukola, P. A. (1986a) ‘An investigation of some factors affecting students’ attitude towards chemistry laboratory’, Journal of Chemical Education, 63, 6, pp 531–532.

Oekebukola, P.A. (1986b) ‘Cooperative learning and students’ attitude to laboratory work’, School Science and Mathematics, 86, 7, pp 582–590.

Olson, D.R. (1973) ‘What is worth knowing and what can be taught’, School Review, 82, pp 27–43.

Orpwood, G.W.F. and Souque, J-P. (1984) Science Education in Canadian Schools, Vol. 1: Introduction and Curriculum Analysis,Ottawa, Science Council of Canada.

Pella, M.O. (1961) ‘The laboratory and science teaching’, The Science Teacher, 28, pp 20–31.

Penick, J.E. (1976) ‘Creativity of fifth grade science students: The effect of two patterns of instruction’, Journal of Research in Science Teaching, 13, pp 307–314.

Penick, J.E. et al. (1976) Science Laboratory Interaction Category (SLIC) — Students,Iowa City, University of Iowa.

Pickering, M. (1980) ‘Are lab courses a waste of time?’, The Chronicle of Higher Education,19 February, p 80.
Raghubir, K.P. (1979) ‘The laboratory investigation approach to science instruction’, Journal of Research in Science Teaching, 16, pp 13–18.
Ramsey, G.A. and Howe, R.W. (1969) ‘An analysis of research in instructional procedure in secondary school science, part II’, The Science Teacher, 36, 4, pp 72–81.
Reif, F. and St John, M. (1979) ‘Teaching physicists thinking skills in the laboratory’, American Journal of Physics, 47, 11, pp 273–276.
Remsen I. (1978) ‘Quoted in the American Chemical Society Publication: guidelines and recommendations for the preparation and continuing education of secondary school teachers of chemistry’, American Journal of Physics, 46, p 734.
Robinson, T.J. (1969) ‘Evaluating laboratory work in high school biology’, The American Biology Teacher, 34, pp 226–229.
Romey, W.D. (1968) Inquiry Techniques for Teaching Science,Englewood Cliffs, NJ, Prentice Hall.
Rosen, S.A. (1954) ‘History of the physics laboratory in the American public schools (to 1910)’, American Journal of Physics, 22, pp 194–204.
Schwab, J.J. (1962) ‘The teaching of science as inquiry’ in Schwab, J.J. and Brandwine, P.F. (Eds) The Teaching of Science,Cambridge, MA, Harvard University Press.
Shulman, L.D. and Tamir, P. (1973) ‘Research on teaching in the natural sciences’ in Travers, R.M.W. (Ed) Second Handbook of Research on Teaching,Chicago, IL, Rand Mc Nally, pp 1098–1148.
Shymansky, J.A. et al. (1976) Science Laboratory Interaction Category (SLIC) — Teacher, Iowa City, University of Iowa.
Shymansky, J.A. and Penick, J.E. (1978) ‘Teachers’ behavior does make a difference in hands-on science classroom’, the 1978 AETS meeting.
Smith, D.M. et al. (1968) ‘Affective response to different media in a multimedia system’, Science Education, 52, pp 16–22.
Tamir, P. (1972) ‘The practical mode: A distinct mode of performance’, Journal of Biological Education, 6, pp 175–182.
Tamir, P. (1974) ‘An inquiry oriented laboratory examination’, Journal of Educational Measurement, 11, pp 23–35.
Tamir, P. (1978) ‘Inquiry and curiosity in biology’, Journal of Biological Education, 12, pp 215–223.
Tamir, P. et al. (1982) ‘The design and use of a practical test inventory’, Journal of Biological Education, 16, pp 42–50.
Tamir, P. (1987) ‘Training teachers to teach effectively in the laboratory’, the AETS meeting, Washington D.C.
Tobin, K. (1986) ‘Secondary science laboratory activities’, European Journal of Science Education, 8, 2, pp 199–211.
Welch, W.W. (1971) ‘A summary of research in science education for the years 1968–69, secondary school level’, Science Education Information Report,Columbus, OH, ERIC.
Wheatley, J.H. (1975) ‘Evaluating cognitive learning in the college science laboratory’, Journal of Research in Science Teaching, 12, pp 101–109.
Woolnough, B. and Allsop, T. (1985) Practical Work in Science,Cambridge, Cambridge Science Education Series, Cambridge University Press.
Yager, R.E. et al. (1969) ‘Effects of the laboratory and demonstration method upon the outcomes of instruction in secondary biology’, Journal of Research in Science Teaching, 5, pp 76–86.
Yager, R.E. (1981) ‘The laboratory in science teaching — main course or dessert?’ in Tarowbridge, L.W. et al.(Eds) Becoming a Secondary School Science Teacher,Columbus, OH, Charles E. Merryl Publishing Co.

Gender and Science Education: I

Bem, S. (1974) ‘The measurement of psychological androgyny’, Journal of Consulting and Clinical Psychology, 42, pp. 155–162.
GASAT I (1981) Raat, J. et al. (Eds) Contributions, Gasat — Conference 1981, Eindhoven, The Netherlands, Eindhoven University Press.
GASAT II (1983) Sjøberg, S. (Ed.) Contributions to the Second Gasat Conference, Oslo, University of Oslo, Centre for Science Education.
GASAT III (1986) Harding, J. (Ed.) Contributions to the Third Gasat Conference, London, King's College.
GASAT IV (1987) Daniels, J.Z. and Kahle, J.B. (Eds) Contributions to the Fourth Gasat Conference, Ann Arbor, MI, University of Michigan.
Gould, S.J. (1981) The Mismeasure of Man, London, W.W. Norton & Co.
Harding, J. (1985) ‘Science and Technology — A future for women?’, paper prepared for the World Conference to Review and Appraise the Achievements of the United Nations Decade for Women, in Nairobi, UNESCO, Paris, July.
Harding, J. (Ed.) (1986) Perspectives on Gender and Science, Lewes, Falmer Press.
Harding, S. and Hintikka, M.B. (Eds) (1983) Discovering Reality: Feminist Perspectives on Epistemology, Metaphysics, Methodology and Philosophy of Science, Dordrecht, Reidel Publishing Company.
Imsen, G. (1987) Motivation Structure and Value Orientation in Women, preliminary report (unpublished), Trondheim, University of Trondheim, Institute of Teacher Training.
Jorde, D. and Lea, A. (1987) ‘Girls in school science’, ongoing project at The Centre for Science Education, University of Oslo.
Kahle, J.B. (1985) ‘Retention of girls in science: Case study of secondary science teachers’ in Kahle, J.B. (Ed.) Women in Science: A Report from the Field, Lewes, Falmer Press.
Kelly, A. , Smail, B. and Whyte, J. (1984) Initial GIST Survey: Results and Implications, Manchester, Girls into Science and Technology.
Keller, E.F. (1985) Reflections on Gender and Science, New Haven, CT, Yale University Press.
Kessler, S.J. and Mc Kenna, W. (1978) Gender: An Ethnomethodological Approach, New York, John Wiley & Sons.
Kvande, E. (1984) Kvinner og hogere teknisk utdanning. Delrapport 2: Integrert eller utdefinert?. (Transl: *Women and Higher Education in Technology. Report 2: Integrated or Out-defined?* Trondheim, Institute for Research on Industrial Environment, IFIM, SINTEF.
Lambert, H.A. (1978) ‘Biology and equality: A perspective on sex differences’, Signs: Journal of Women in Culture and Society, 4, pp. 97–117.
Lehrke, M. et al. (Ed.) (1985) Interests in Science and Technology Education, Kiel, Institut für die Pädagogik der Naturwissenschaften.
Lie, S. and Sjøberg, S. (1984) ‘Myk’ jenter i ‘harde’ fag? (Trans: Soft girls in hard science?) Oslo, Universitetsforlaget.
Matyas, M.L. (1985) ‘Factors affecting female achievement and interest in science and scientific careers’ in Kahle, J.B. (Ed.) Women in Science: A Report from the Field, Lewes, Falmer Press.

Rokeach, M. (1983) The Nature of Human Values, London, Collier Macmillan Publishers.
Sjøberg, S. (1986) Naturfag og norsk skole. Elever og loerere sier sin menign. (Transl: Science and Norwegian Schools. Pupils and Teachers Express Their Opinion). Oslo, Universitets-forlaget.
Skog, B. (1983) ‘Curricular options — A barrier against women's participation in scientific and technological work?’, in Gasat ii (1983).
Skog, B. (1987) Valgfrihet of Likhetsidealer. (Transl: Freedom of Choice and Ideas of Equity). Project report, Trondheim, Institute of Sociology, University of Trondheim.
Smithers, A. and Collings, J. (1981) ‘Girls studying science in the sixth form’, in Kelly, A. (Ed.) The Missing Half, Manchester, Manchester University Press, pp. 164–179.
Ziman, J. (1980) Teaching and Learning about Science and Society, Cambridge, Cambridge University Press.

Gender and Science Education II

American Association of Colleges (AAC) (1982) ‘The classroom climate: A chilly one for women?’ Project on the Status and Education of Women. Washington, DC, AAC, pp. 1–22.
American Association of Colleges (AAC) (1986) Project on the Status and Education of Women, Washington, DC, AAC, 14, 4, 8.
Chambers, D.W. (1983) ‘Stereotypic images of the scientist: The draw-a-scientist test’, Science Education, 67, pp. 255–265.
Delamont, S. (1983) ‘The conservative school? Sex roles at home, at work and at school’ in Walker, S. and Barton, L. (Eds) Gender, Class and Education, Lewes, Falmer Press.
Eccles, J.S. (1985) ‘Sex differences in achievement patterns’ in Sonderegger, T. (Ed) Nebraska Symposium of Motivation, Vol. 2, Lincoln, University of Nebraska Press.
Friedlander, N. (1986) ‘Why physics fails to woo the female’, The Australian, 10 November, p. 15.
Gardner, A.L. (1986) ‘Effectiveness of strategies to encourage participation and retention of precollege and college women in science’, unpublished doctoral dissertation, West Lafayette, IN, Purdue University.
Garratt, L. (1986) ‘Gender differences in relation to science choice at A-level, Educational Review, 38, 1, pp. 67–76.
Hildebrand, G.M. (1987) ‘Girls and the career relevance of science: A case study’, unpublished Master's thesis, Melbourne, Monash University.
Hornig, L.S. (1987) ‘Women graduate students: A literature review and synthesis’ in Dix, L.S. (Ed) Women: Their Underrepresentation and Career Differentials in Science and Engineering Washington, DC, National Academy Press, pp. 103–126.
Hyde, S. (1986) ‘Girls and science — strategies for change’, Pivot, 3, pp. 28–30.
Iliams, C. (1985) ‘Early school experience may limit participation of women in science’, Contributions to the Third GASAT Conference, London, Chelsea College.
Irvine, J. and Martin, B. (1986) ‘Women in radio astronomy — shooting the stars?’ in Harding, J. (Ed.) Perspectives on Gender and Science, London, Falmer Press, pp. 80–102.
Johnson, S. and Murphy, P. (1986) ‘Girls and physics: Reflections on APU Findings’, APU Occasional Paper No. 4, London, University of Leeds and Kings College.
Johnston, S. (1984). ‘Girls need a science education too’, Australian Science Teachers Journal, 30, 2, pp. 18–23.
Kahle, J.B. (1983) ‘Factors affecting the retention of girls in science courses and careers: Case studies of selected secondary schools’, Final Report (NSF 83-SP-0798), Washington, DC, National Science Foundation.
Kahle, J.B. (1985) ‘Retention of girls in science: Case studies of secondary teachers’ in Kahle, J.B. (Ed) Women in Science: A Report from the Field, Lewes, Falmer Press, pp. 193–229.
Kahle, J.B. (1986) ‘Equitable science education: A discrepancy model’, Haydn Williams public lecture, Perth, Western Australian Institute of Technology, 17 October.
Kahle, J.B. (in press) ‘SCORES: A project for change’, International Journal of Science Education.
Kahle, J.B. and Lakes, M.K. (1983) ‘The myth of equality in science classrooms’, Journal of Research in Science Teaching, 20, pp. 131–140.
Keller, E.F. (1986) ‘How gender matters: Or, why it's so hard for us to count past two’ in Harding, J. (Ed.) Perspectives on Gender and Science, Lewes, Falmer Press, pp. 168–183.
Kelly, A. (1985) ‘The construction of masculine science’, British Journal of Sociology of Education, 6, 2, pp. 133–153.
Kelly, A. , Whyte, J. and Smail, B. (1984) Final Report of the GIST Project. Manchester, University of Manchester, Department of Sociology.
Leinhardt, G. , Seewald, A.M. and Engel, M. (1979) ‘Learning what's taught: Sex differences in instruction’, Journal of Educational Psychology, 71, pp. 432–439.
Linn, M.C. , DE Benedictis, T. , Delucchi, K. , Harris, A. and Stage, E. (1987) ‘Gender differences in national assessment of education progress science items: What does “I don't know” really mean?’, Journal of Research in Science Teaching, 24, 3, pp. 267–278.
Long, J.S. (1987) ‘Discussion: Problems and prospects for research on sex differences in the scientific career’ in Dix, L.S. (Ed) Women: Their Underrepresentation and Career Differentials in Science and Engineering, Washington, DC, National Academy Press, pp. 163–170.
MAC Donald, M. (1980) ‘Schooling and the reproduction of class and gender relations’ in Barton, L. , Meighan, R. and Walker, S. (Eds) Schooling, Ideology and the Curriculum, Lewes, Falmer Press.
Mason, C.L. (1986) ‘Student attitudes toward science & science-related careers: An investigation of the efficacy of a high school biology teachers’ intervention program’, unpublished doctoral dissertation, West Lafayette, IN, Purdue University.
Matyas, M.L. (1985) ‘Obstacles and constraints on women in science’, in Kahle, J.B. (Ed) Women in Science: A Report from the Field, Lewes, Falmer Press, pp. 77–101.
Mead, M. and Metreaux, R. (1957) ‘The image of the scientist among high school children’, Science, 126, pp. 384–389.
Mullins-Gunst, K. (1985) ‘An analysis of Australian chemistry textbooks’, Contributions to the Third GASAT Conference, London, Chelsea College, University of London.
National Science Foundation (NSF) (1986) Women and Minorities in Science and Engineering (NSF 86–301), Washington, DC, National Science Foundation.

Newton, P. (1986) ‘Female engineers: Femininity redefined?’ in Harding, J. (Ed.) Perspectives on Gender and Science, Lewes, Falmer Press, pp. 40–61.
Parker, L.J. (1985) ‘Non-sexist science education: An issue of primary concern’, paper presented at the Science Teachers Association of Victoria Conference, Monash University, Melbourne, Australia, December.
Parker, L.H. and Rennie, L.J. (1986) ‘Sex-stereotyped attitudes about science: Can they be changed?’, European Journal of Science Education, 8, 2, 173–183.
Rennie, L.J. (1986). ‘The image of a scientist: Perceptions of preservice teachers’, unpublished paper, University of Western Australia.
Rennie, L.J. , Parker, L.H. and Hutchinson, P.E. (1985) ‘The effect of inservice training on teacher attitudes and primary school science classroom climates’, Research Report Number 12, University of Western Australia.
Rossiter, M.W. (1982) Women Scientists in America: Struggles and Strategies to 1940, Baltimore, MD, Johns Hopkins University Press.
Rowell, J.A. (1971) ‘Sex differences in achievement in science and the expectations of teachers’, The Australian Journal of Education, 15, 1, pp. 16–29.
Sadker, D. , and Sadker, M. (1985) ‘Is the OK classroom, OK?, Phi Delta Kappan, 55, pp. 358–361.
Schibeci, R.A. (1986) ‘Images of science and scientists and science education’, Science Education, 70, pp. 139–149.
Smail, B. (1985) ‘An attempt to move mountains: The “girls into science and technology” (GIST) project’, Journal of Curriculum Studies, 17, pp. 351–354.
Spear, M.G. (1984) ‘Sex bias in science teachers’ ratings of work and pupil characteristics’, European Journal of Science Education, 6, pp. 369–377.
Tobin, K. and Gallagher, J.J. (1987) ‘The role of target students in the science classroom’, Journal of Research in Science Teaching, 24, pp. 61–75.
Tobin, K. and Garnett, P. (1986) ‘Gender differences in science activities’, unpublished paper’, Bentley, Western Australian Institute of Technology.
Vandervoort, F.S. (1985) ‘Women's role in professional scientific organizations: Participation and recognition’ in Kahle, J.B. (Ed.) Women in Science: A Report from the Field, Lewes, Falmer Press.
Vetter, B.M. (1987) ‘Women's progress’, Mosaic 18, 1, pp. 2–9.
Webb, N.M. (1984) ‘Sex differences in interaction and achievement in cooperative small groups’, Journal of Educational Psychology, 76, pp. 33–44.
Weinreich-Haste, H. (1981) ‘The image of science’ in Kelly, A. (Ed.) The Missing Half, Manchester, Manchester University Press.
Whyte, J. (1986) Girls into Science and Technology, London, Routledge & Kegan Paul.
Zuckerman H. (1987) ‘Persistence and change in the careers of men and women scientists and engineers: A review of current research’ in Dix, L.S. (Ed.) Women: Their Underrepresentation and Career Differentials in Science and Engineering, Washington, DC, National Academy Press, pp. 127–162.

The Dilemma of Science, Technology and Society Education

Addinell, S. and Solomon, J. (1983) Science in a Social Context, Teachers Guide, Hatfield, Association for Science Education.
Aikenhead, G. (1979) ‘Science: A way of knowing’, The Science Teacher, 46, 6.
Aikenhead, G. (1988) ‘Student belief about science-technology-society: Four different modes of assessment, and sources of students’ viewpoints’, Journal of Research Science Teaching, in press.
Aikenhead, G. and Fleming, R. (1975) Science a Way of Knowing, Saskatoon, University of Saskatchewan, Department of Curriculum Studies.
Assessment of Performance Unit (1987) Age 13 Review, London, DES.
Association for Science Education (1979) Alternatives for Science Education, Discussion Paper, Hatfield, Association for Science Education.
Association for Science Education (1981) Education through Science, Policy Document, Hatfield, Association for Science Education.
Bybee, R.W. , Harms, N. , Ward, B. and Yager, R. (1980) ‘Science society and science education’, Science Education, 64, 3, pp. 377–395.
Dreyfuss, A. and Jungwirth, E. (1980) ‘A comparison of the “prompting effect” of out-of-school with that of in-school contexts on certain aspects of critical thinking’, European Journal of Science Education, 2, 3, pp. 301–310.
Ellingham, H. and Langton, N. (1975) ‘The power station game’, Physics Education, 10, pp. 445–447.
Eijkelhof, H. (1985) ‘Dealing with acceptable risk in science education’, paper presented to the conference ‘Science Education and Future Human Needs’, Bangalore.
Fleming, R. (1986) ‘Adolescent reasoning in socio-scientific issues, Part I’, Journal of Research Science Teaching, 23, 8, pp. 677–688.
Hall, W. (1973) Science and Decision-making, London, Longman and Harmondsworth, Penguin.
Harding, J. (1986) ‘The making of a scientist?’ in Harding, J. (Ed.) Perspectives of Gender and Science, Lewes, Falmer Press.
Head, J. (1980) ‘A model to link personality to a preference for science’, European Journal of Science Education, 2, pp. 295–300.
Henle, M. (1962) ‘The relationship between logic and thinking’, Psychological Review, 69, pp. 366–378.
Hines, J.M. and Hungerford, H.R. (1984) ‘Environmental educational research related to environmental action skills’ in Monographs in Environmental Education and Environmental Studies (1971–1982) ERIC, Ohio State University, pp. 113–130.
Holman, J. (1987) ‘Resources or courses? Contrasting approaches to the introduction of industry and technology to the secondary curriculum’, School Science Review, 68, 244, pp. 432–438.
Hufstedler, S.M. and Langenberg, D.N. (1980) Science Education for the 1980s and Beyond, Washington, DC, National Science Foundation and the Department of Education.
Iozzi, L. (1979) ‘Moral judgment, verbal ability, logical reasoning ability, and environmental issues’, unpublished PhD thesis, Rutgers University, NJ.
Jevons, F. (1967) ‘A science greats’, Physics Education, 2, p. 196.
Layton, D. (1982) Science Education and Values Education — An Essential Tension in proceedings of an international seminar, London, Chelsea College.

Lewis, J. (1980) Science in Society. Readers and Teachers' Guide, Hatfield, Association for Science Education and London, Heinemann.

McConnell, M.C. (1982) 'Teaching about science, technology and society at the secondary school level in the United States', Studies in Science Education, 9, pp. 1–32.

MCQuail, D. (1983) Mass Communication Theory: An Introduction, London, Sage Publications.

McQuail, D. , Blumer, J. and Brown, J. (1972) 'The television audience: A revised perspective' in Mc Quail, P. (Ed.) Sociology of Mass Communication, Harmonds-worth, Penguin, pp. 135–165.

Maple, J. (1986) 'An investigation of the transferability of practical skills', unpublished MSc thesis, Oxford, University of Oxford.

Rip, A. (1978) 'The social context of science, technology and society courses in the universities' in Boeker, E. and Gibbons, M. (Eds) Science, Society and Education, Amsterdam, Vrie Universiteit, pp. 135–152.

Schutz, A. and Luckman, T. (1973) The Structure of Life World, Evanston, ILL, Northwestern University Press.

Solomon, J. (1983) Eight titles in the SISCON in Schools series and a Teachers' Guide, Hatfield, Association for Science Education and Oxford, Basil Blackwell.

Solomon, J. (1985) 'Learning and evaluation: A study of school children's views on the social uses of energy', Social Studies of Science, pp. 343–371.

Spiegel-Rosing, I. and Price, D.D.E.S. (Eds) (1977) Science, Technology and Society: A Cross-disciplinary Perspective, Beverly Hills, CA, Sage.

Weisenmayer, R.L. , Murrin, M.A. and Tomera, A.N. (1984) 'Environmental educational research related to issue awareness' in Monographs in Environmental Education and Environmental Studies (1971–1982) ERIC, Ohio State University, pp. 61–94.

Ziman, J. (1980) Teaching and Learning about Science and Society, Cambridge, Cambridge University Press.

Zoller, U. (1985) 'Interdisciplinary decision-making in the science curriculum in the modern socio-economic context' in Harrison, G. (Ed.) World Trends in Science and Technology Education, report on second international symposium, Nottingham, Trent Polytechnic.