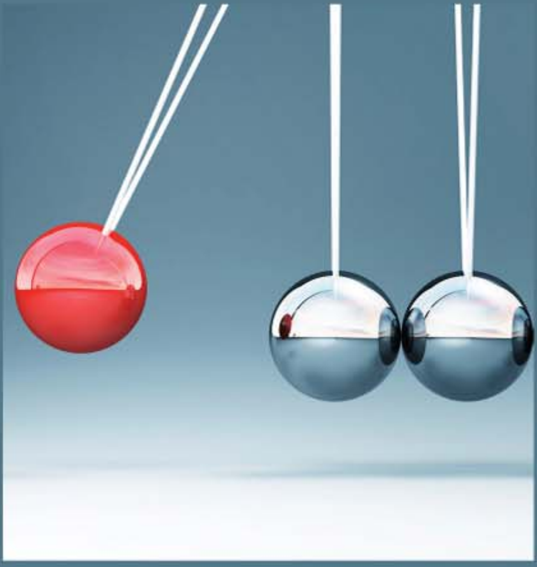
SCIENCE TEACHING

The Contribution of History and Philosophy of Science

20TH ANNIVERSARY REVISED AND EXPANDED EDITION



Michael R. Matthews

ROUTLEDGE

Science Teaching

'This is a transformative book. It provides an enlightening cartography of the uses of history and philosophy in the science classroom. No one interested in science teaching or science culture should be without a copy of this updated classic.'

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The CUNY Graduate Center and Queens College CUNY, USA

'This book's importance transcends science education. Its coverage of topics such as the impact of constructivism on education provides the book with a universal importance. I strongly recommend it to everyone interested in teaching and learning.'

John Sweller, School of Education,
University of New South Wales, Australia

'The Pendulum chapter is a masterpiece! It should be considered obligatory reading for everyone who aims at becoming a science (especially physics) teacher.'

Ricardo Karam, Physikdidaktik,
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'Science Education is a rigorous and necessary resource for science education researchers, policy makers and practitioners.'

Sibel Erduran, School of Education,
University of Limerick, Ireland

Michael R. Matthews is an Honorary Associate Professor in the School of Education at the University of New South Wales, Australia. He is Founding Editor of the international journal *Science & Education*; Founding President of the International History, Philosophy and Science Teaching Group; and President of the Inter-Divisional Teaching Commission of the International Union of History and Philosophy of Science. He has trained, taught and published in science education and in history and philosophy of science.

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Science Teaching

The Contribution of History and Philosophy of Science

20th Anniversary Revised and Expanded Edition

Michael R. Matthews

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For my daughters: Clare, Alice and Amelia

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Preface (2014)

It is a pleasure to see the twentieth anniversary of my 1994 *Science Teaching* book being celebrated by publication of an updated and enlarged edition. The book has stayed in print for 20 years, which suggests that it has some merit. The intellectual background to the book is described in the following 1994 Preface. Pleasingly, if philosophical arguments are any good, then they retain their merit for a long time. Having 'philosophical merit' is, of course, not the same as 'being correct', but it does mean being clear enough to enable readers to see where the mistakes are (this issue of clarity in communication and argument will be something returned to in Chapter 12). The central conviction of the first edition was stated in its Preface:

> For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instils a concern for evidence, and for having ideas judged not by personal or social interest, but by how the world is; a sense of 'Cosmic Piety', as Bertrand Russell called it. These values are under attack both inside and outside the academy. Some educationally influential versions of postmodernism and constructivism turn their back on rationality and objectivity, saying that their pursuit is Quixotic. This is indeed a serious challenge to the profession of science teaching.
>
> The vitality of the scientific tradition, and its positive impact on society, depends upon children being successfully introduced to its achievements, methods and thought processes, by teachers who understand and value science. The history and philosophy of science contribute to this understanding and valuation.

World events and educational developments in the subsequent 20 years have only strengthened these convictions. The 'flight from science' has continued unabated and has been extensively documented in US and European government reports. There have been continuing debates over many socio-scientific issues, such as the utilisation of stem cells from manufactured human embryo cells, the control or utilisation of genetically modified crops, the reality and mitigation of androgenic global warming, harnessing or otherwise of nuclear energy, and compulsory child vaccination. With economic and cultural globalisation, serious questions have been asked about the supposed universality of science and of the justification and utility of teaching orthodox science in cultures that have their own rich lore of understandings of nature and non-scientific worldviews. After the 1960s' Kuhnian trumpet blast, various postmodernist waves have swept through the academy, including schools of education, each disputing the traditional foundations for science teaching. And there are many other such pressing issues, all of which have philosophical dimensions.

There have been constant wars in the Middle East, Africa and the Indian subcontinent, fuelled by ideology, but fought with high-tech, science-enabled weaponry. Each drone attack, each report of the use of oxygen-deprivation bombs, to say nothing of ordinary bombs and napalm, each poison-gas attack brings into focus the values of science, the responsibility of scientists and the purpose of science teaching. Understanding these events and issues, and then appropriately responding to them, requires a degree of rational, critical and objective analysis; the way forward is not advanced by embracing irrational, uncritical and subjective thinking. These intellectual and personal capacities – scientific habits of mind or scientific temper – can be developed in science classrooms, if the curriculum and pedagogy are informed by the history and philosophy of science (HPS).

Since the book's first edition, there have been considerable developments in science-education curricula that explicitly recognise the importance of teaching the philosophical, cultural and historical dimensions of science. In the United States, the first-ever National Science Education Standards were published by the National Research Council in 1996 (National Research Council 1996). These standards recognise the centrality of philosophical and historical knowledge in the teaching of science. In the UK, a group of prominent science educators, reflecting on Britain's National Curriculum and the most appropriate form of science education for the new millennium, wrote a report with ten recommendations, the sixth of which said that: 'The science curriculum should provide young people with an understanding of some key ideas about science, that is, ideas about the ways in which reliable knowledge of the natural world has been, and is being, obtained' (Millar & Osborne 1998, p.20). Different European and Asian countries have comparable statements about desired broader and deeper outcomes of school science.

Clearly, the goals of the US National Standards, the UK group and other national groups can only be realised if science teachers have some familiarity and enthusiasm for the history and philosophy of their subject. A position paper of the US Association for the Education of Teachers in Science, the professional association of those who prepare science teachers, has recognised this in its own recommendation that: 'Standard 1d: The beginning science teacher educator should possess levels of understanding of the philosophy, sociology, and history of science exceeding that specified in the [US] reform documents' (Lederman *et al.* 1997, p.236).

The arguments advanced by the above curriculum writers are basically the same as those advanced in the first edition of this book.

Along with curriculum developments, there has been, in the past 20 years, a significant amount of interdisciplinary research in the field of HPS and science teaching (HPS&ST). This research makes contributions to three categories of question faced by science teachers:

1 *theoretical* questions that impinge on science education, such as: constructivist claims about the knowledge claims of science, feminist critiques of science, the status of indigenous or local sciences and how they should or should not be taught in science programmes, science and religion, the status of models in science, scientific values and their relation to cultural values, and so on;
2 *curriculum* questions about the structure, content and scheduling of school science programmes;
3 *pedagogical* questions about how the utilisation of historical and philosophical material affects student motivation, interest and learning *of* science and *about* science.

The major development in HPS&ST research since the 1994 publication has been the establishment and continued growth of the journal *Science & Education: Contributions from History, Philosophy and Sociology of Science and Education*. The journal is now in its twenty-third year of publication, with ten issues being published per year (www.springerlink.com). About 800 research papers have been published; in 2011, there were 108,650 article downloads from the journal's website, and it is noteworthy that the most downloads are from Asia.

A core part of the HPS&ST infrastructure has been the International History, Philosophy and Science Teaching Group (IHPST) (www.ihpst.net). The group has been associated with the journal; it held its inaugural meeting in Tallahassee in 1989 and has continued to hold successful biennial conferences,[1] with select proceedings published in the journal;[2] and it has commenced a programme of biennial regional meetings in Latin America and Asia.[3] These are attended by teachers, educators, historians, philosophers and cognitive scientists.

The vitality and international reach of current HPS&ST scholarship and engagement is manifest in the three-volume, seventy-six-chapter *International Handbook of Research in History, Philosophy and Science Teaching* (Matthews 2014). It has sections on Pedagogical Studies, Theoretical Studies, National Studies and Biographical Studies and is contributed to by 125 authors from thirty countries and contains 11,000 references. Many of the issues and debates 'touched on' in this book are developed at length in chapters of the *Handbook*.

This book has three core purposes: one, to show educators that HPS is an interesting and engaging subject, and that it can usefully illuminate many of the theoretical, curricular and pedagogical issues that they encounter; two, to show historians and philosophers that their own expertise and scholarship can be utilised in science-education debates, curriculum development and classroom teaching; and three, to cultivate a sense among science teachers of belonging and contributing to the scientific and philosophical tradition that has had such enormous international social and cultural influence. Everyone should be mindful that, without science teachers, there would be no science. I have tried as much as possible to provide extended quotations from the main scholars discussed – Aristotle, Galileo, Huygens, Newton, Priestley, Mach and others – so that something of their own voice can be heard; too often, the names are known, but their voices are not heard; quotations are a meagre way of giving them some expression.

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Sydney 2052, Australia
February 2014

Notes

1 These were: Minneapolis 1995, Calgary 1997, Pavia 1999, Denver 2001, Winnipeg 2003, Leeds 2005, Calgary 2007, Notre Dame 2009, Thessaloniki 2011 and Pittsburgh 2013.
2 For select proceedings, see: Pavia (Vol.10, Nos. 1–2, 2001), Winnipeg (Vol.14, Nos. 3–5, 2005), Leeds (vol.16, nos. 2–4, 2007), Calgary (Vol.18, Nos. 3–4, 2009), Notre Dame (vol.20, nos. 7–8, 2011) and Thessaloniki (Vol.22, No. 6, 2013).
3 Brazil (2010), Argentina (2012), Korea (2012) and Taiwan (2014).

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Matthews, M.R. (ed.): 2014, *International Handbook of Research in History, Philosophy and Science Teaching*, 3 volumes, Springer, Dordrecht, The Netherlands.
Millar, R. and Osborne, J.: 1998, *Beyond 2000: Science Education for the Future*, School of Education, King's College, London.
NRC (National Research Council): 1996, *National Science Education Standards*, National Academies Press, Washington, DC.

Preface (1994)

This book seeks to contribute to science teaching and science-teacher education by bringing the history and philosophy of science and science teaching into closer contact. My belief is that science teaching can be improved if it is infused with the historical and philosophical dimensions of science. Such contextual, or liberal, teaching of science in schools benefits both those students going on to further study of science, and those, the majority, for whom school science is their last contact with formal science instruction.

The conviction that the learning of science needs to be accompanied by learning about science is basic to liberal approaches to the teaching of science. This position has been eloquently argued by, among others, Ernst Mach, James Conant, Gerald Holton, Joseph Schwab and Martin Wagenschein. This book is a housekeeping effort in the liberal tradition: it attempts to survey the history of debate on the matter; to list the chief publications; to itemise contemporary relevant research, particularly in children's learning of science; to point to present-day practical and theoretical problems in science education to which the history and philosophy of science can contribute; to give an account of curriculum developments embodying the liberal spirit of science instruction; and to indicate ways in which the history and philosophy of science can be usefully included in teacher preparation programmes.

This book is the work of an under-labourer in the garden, to use John Locke's expression. Some furrows have been made, and some seeds planted. Hopefully, other people will water the garden, straighten the furrows, plant other seeds and remove some of the weeds. If the book stimulates science teachers at both schools and universities to be more interested in the history and philosophy of science, and encourages historians, philosophers and sociologists of science to become interested and involved with science education, then it will have achieved one purpose. If it contributes to the inclusion of HPS studies in science-teacher education programmes, it will have achieved another purpose. If it promotes an interest in educational theory among science educators, it will have achieved still another.

The theme of this book is that science teachers need three competencies: first, knowledge and appreciation of science; second, some understanding of HPS in order to do justice to the subject they are teaching and to teach it well, and in order to make intelligent appraisals of the many theoretical and educational debates that rage around the science curriculum; third, some educational theory or vision that can inform their classroom activities and relations with students, and provide a rationale and purpose for their pedagogical efforts. Science teachers contribute to the overall education of students, and thus they need some moderately well-formed view of what education is, and the goals it should be pursuing. Teachers need to keep their eyes on the educational prize, the more so when social pressures increasingly devalue the intellectual and critical traditions of education.

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

This flight from the science classroom, by both teachers and students, has been depressingly well documented. In the US in the mid 1980s, it was estimated that, each year, 600 science graduates entered the teaching profession, while 8,000 left it (Mayer 1987). In 1986, 7,100 US high schools had no course in physics, and 4,200 had no course in chemistry (Mayer 1987). In 1990, only four states required the three years of basic science recommended by the sobering 1983 report *A Nation at Risk*; the rest allowed high-school graduation with only two years of science (Beardsley 1992, p.80). Irrespective of years required, 70 per cent of all school students drop science at the first available opportunity – which is one reason why, in 1986, fewer than one in five high-school graduates had studied any physics. In 1991, the Carnegie Commission on Science, Technology and Government warned that the failings of science education were so great that they posed a ‘chronic and serious threat to our nation’s future’ (Beardsley 1992, p.79). In the UK, recent reports of the National Commission on Education and the Royal Society have both documented similar trends. One commentator has said that, ‘wherever you look, students are turning away from science . . . Those that do go to university are often of a frighteningly low calibre’ (Bown 1993, p.12). In Australia, in 1989, science-education programmes had the lowest entrance requirement of all university degrees.

There are complex economic, social, cultural and systemic reasons for this rejection of science. These are beyond the scope of teachers to rectify. But there are also educational reasons for the rejection of science that are within the power of teachers and administrators to change. In 1989, for example, a disturbing number of the very top Australian school science achievers gave ‘too boring’ as the reason for not pursuing university science. It is these curriculum and pedagogical failings that the history and philosophy of science (HPS) can help rectify.

One part of this contribution by HPS is to connect topics in particular scientific disciplines, to connect the disciplines of science with each other, to connect the sciences generally with mathematics, philosophy, literature, psychology, history, technology, commerce and theology; and finally, to display the interconnections of science and culture – the arts, ethics, religion, politics – more broadly. Science has developed in conjunction with other disciplines; there has been mutual interdependence. It has also developed, and is practised, within a broader cultural and social milieu. These interconnections and interdependencies can be appropriately explored in science programmes, from elementary school through to graduate study. The result is far more satisfying for students than the unconnected topics that constitute most programmes of school and university science. Courses in the sciences are too often, as one student remarked, 'forced marches through unknown country without time to look sideways'.

The defence of science in schools is important, if not necessary, to the intellectual health of society. Pseudoscientific and irrational worldviews already have a strong hold on Western culture; anti-science is on the rise. It is not just the ramparts of society that have been invaded – witness the checkout-counter tabloids with their 'Elvis lives' stories, Gallup polls showing that 40 per cent of the adult US population believe that human life began on Earth just a couple of thousand years ago, and astrology columns in every newspaper. But the educational citadel has been compromised – a small, and hopefully not representative, 1988 survey of US biology teachers revealed that 30 per cent rejected the theory of evolution, and 22 per cent believed in ghosts (Martin 1994). For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instills a concern for evidence, and for having ideas judged, not by personal or social interest, but by how the world is; a sense of 'Cosmic Piety', as Bertrand Russell called it. These values are under attack both inside and outside the academy. Some educationally influential versions of postmodernism and constructivism turn their back on rationality and objectivity, saying that their pursuit is Quixotic. This is, indeed, a serious challenge to the profession of science teaching.

The vitality of the scientific tradition, and its positive impact on society, depends upon children being successfully introduced to its achievements, methods and thought processes, by teachers who understand and value science. The HPS contribute to this understanding and valuation.

This book grows out of, and is a contribution to, the International History, Philosophy, and Science Teaching Group. This is a heterogeneous group of teachers, scientists, educators, historians, mathematicians, philosophers of education and philosophers of science who, over the past 5 years, have staged two conferences[1] and have arranged the publication of many special issues of academic journals devoted to HPS and science teaching.[2] Some basic papers in the field have been gathered together and published in Matthews (1991), *History, Philosophy, and Science Teaching: Select Readings* (OISE Press, Toronto, and Teachers College Press, New York, 1991). These might be useful for further reading. The International History, Philosophy, and Science Teaching Group is also associated with a new journal devoted to the subject of this book – *Science & Education: Contributions from the History, Philosophy, and Sociology of Science and Mathematics*.[3]

Notes

1 The proceedings of the 1989 Tallahassee conference are available in Herget (1989, 1990); those of the 1992 Kingston conference are in Hills (1992).
2 The journal special issues include the following: *Educational Philosophy and Theory* 20(2), (1988); *Synthese* 80(1), (1989); *Interchange* 20(2), (1989); *Studies in Philosophy and Education* 10(1), (1990); *Science Education* 75(1), (1991); *Journal of Research in Science Teaching* 29(4), (1992); *International Journal of Science Education* 12(3), (1990); and *Interchange* 23(2,3), (1993).
3 The journal is published by Kluwer Academic Publishers, PO Box 17, 3300 AA Dordrecht, The Netherlands. It is available at reduced rates through the international HPS&ST group (inquiries to the author).

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Acknowledgements

Acknowledgements (2014)

The bulk of personal debts for this twentieth anniversary edition of my 1994 book are the same as those for the original. First, as with all book writing, families pay a price. Since 1994, my wife, Julie, and Clare and Alice have been joined by a third daughter, Amelia, and two grandchildren, Joshua and Elenore. All have seen my time taken up with this project and have, pleasingly, taken it on faith that I have been doing something worthwhile. It is for readers to judge whether my time would have been better spent with my family.

Writing this second edition has been a wonderful opportunity to revisit and re-evaluate thoughts and arguments that were originally written in response to a 1989 invitation from Israel Scheffler to write a book on science teaching for his Routledge Philosophy of Education Research Library. Neither of us could have thought that the book would stay in print for so long, or that, 25 years later, a second edition would be warranted.

In 1994, I mentioned my debt to teachers who first introduced me to the subject matter of the book: at the University of Sydney, Wallis Suchting (Philosophy) and Bill Andersen (Education); at Boston University, Robert S. Cohen, Abner Shimony and Marx Wartofsky (Philosophy). Clearly, the debt to learned and capable early teachers always remains. In the 20 years since the first edition, I have learned things from a number of scholars whom I have had the good fortune to meet and engage with. Among these, Mario Bunge warrants particular mention. Now enjoying his ninety-fourth year, he continues to write books and articles that move easily, but with great erudition, across history of philosophy, science and philosophy of science, always with an admirable clarity of expression and a willingness to engage with serious educational issues.

In 1994, I mentioned my good fortune to edit the journal *Science & Education*, which then was in its second year of publication. Twenty years later, I am still editing the journal, and it has put me in contact with hundreds of scholars, from scores of countries around the world. These have been a great source of ideas and a privileged way of being kept abreast of current research, even if this knowledge has not always been internalised in ways that it deserved to be.

In 1994, I also mentioned my debt to the IHPST. This debt has simply grown by a further 20 years of valuable and intellectually productive friendships. Of special note have been the meetings held in Greece, Finland, Argentina, Brazil, Mexico, Denmark, Spain, India and Korea – these have all been wonderful occasions for discussing and hearing about history, philosophy and science teaching in contexts outside the dominant Anglo-American sphere. Within the latter sphere, for the past 20 years, the biennial IHPST meetings have been themselves happy and enormously productive gatherings, characterised by the admirable mix of serious scholarship and good fellowship.

I have benefited significantly from my editorship of the seventy-six-chapter, three-volume *Handbook of Research in History, Philosophy and Science Teaching* (Springer 2014), which has been contributed to by 125 authors from thirty countries. My debt is plainly visible in the Reference list for each of this book's chapters. The present book could be regarded as a 'primer' for the larger handbook; all of the arguments here, and more, are developed and documented at considerable length in the latter work.

Many friends have read and commented on different chapters of this book: Ricardo Karam, Yann Benétreau-Dupin, Colin Gauld, Robert Nola, Roland Schulz, Edgar Jenkins and Gürol Irzik. I am indebted to them, as are readers, for their suggestions and corrections. Julie House and Hans Schneider pleasingly corrected and copy-edited different chapters. A particular debt is owed to Paul McColl, who closely read, made valuable suggestions for, and carefully copy-edited the entire manuscript: a heroic task. Special thanks are due to the diligence and professional competence of Louise Smith, a Routledge-contracted UK copy-editor, who even after all the foregoing reading and corrections, nevertheless raised 110 'author queries' for me to rectify. Readers have been saved a good deal of frustration by these 110 lapses not finding their way into print. I commend her services to any author.

Finally, this book would not have happened except for the kind invitation of Naomi Silverman, the Routledge Taylor & Francis Education Editor, to write a second and enlarged edition of the 1994 book. Working with her has been a very happy and easy experience; I commend her to all authors.

Sources

In a number of places, this enlarged edition has drawn on material I have published over the past 20 years, specifically:

- Chapter 6 is partly dependent on: Matthews, M.R.: 2001, 'Methodology and Politics in Science: The Case of Huygens' 1673 Proposal of the Seconds Pendulum as an International Standard of Length and Some Educational Suggestions', *Science & Education* 10(1–2).
- Chapter 7 is partly dependent on: Matthews, M.R.: 2009, 'Science and Worldviews in the Classroom: Joseph Priestley and Photosynthesis', *Science & Education* 18(6–7).

- Chapter 10 is partly dependent on: Matthews, M.R.: 2009, 'Teaching the Philosophical and Worldview Components of Science', *Science & Education* 18(6–7).
- Chapter 11 is partly dependent on: Matthews, M.R.: 2012, 'Changing the Focus: From Nature of Science (NOS) to Features of Science (FOS)'. In M.S. Khine (ed.) *Advances in Nature of Science Research*, Springer, Dordrecht, The Netherlands.
- Chapter 12 is partly dependent on: Matthews, M.R.: 2014, 'Discipline-based Philosophy of Education and Classroom Teaching', *Theory and Research in Education* 12(1), 19–108.

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Chapter 1

The Rapprochement Between History, Philosophy and Science Education

Science has been the foremost contributor to our understanding of the natural and social world, and, through its engagement with religion, worldviews, economies and technologies, it has been a major influence on culture. Food production, medicine, entertainment, war, industry, reproduction, transportation, accommodation, religion, space exploration, and people's self-understanding and their worldviews – their sense of place in the universe and in nature – have all been profoundly affected by science – mostly for good; sometimes for bad. Understanding the 'balance sheet' is of utmost importance, and this understanding is only possible with knowledge of the history and philosophy of science (HPS). This chapter will mention some of the elements that constitute the current rapprochement between history, philosophy and science teaching, or components of the 'HPS&ST programme', as it might be called. These include:

- the significant engagement of historians and philosophers with theoretical, curricular and pedagogical issues in science teaching;
- the growth of liberal education and the recognition of the historical and philosophical components necessary for this education;
- the acknowledgement of the requirement of basic philosophy for good technical science education;
- the recognition that HPS can contribute to ameliorating some of the widespread and well-known problems of science education;
- the realisation that HPS is a necessary condition for achieving any 'flow-on' effects from science learning for solving major issues in personal and social life;
- the realisation that HPS knowledge is required for meeting the explicit requirements of many new national and provincial science curricula.

Philosophers and Historians Engage with Science Education

Thirty-five years ago, Robert Ennis wrote a comprehensive review of the extant literature on philosophy of science and science teaching. His review listed six questions that science teachers constantly encounter in their classrooms and staffrooms, questions that the deliberations and researches of philosophers and historians of science could illuminate. These questions were:

- What characterises the scientific method?
- What constitutes critical thinking about empirical statements?
- What is the structure of scientific disciplines?
- What is a scientific explanation?
- What role do value judgements play in the work of scientists?
- What constitute good tests of scientific understanding?

These questions are of perennial concern to science teachers and science-teacher education programmes. However, Ennis made the melancholy observation that: 'With some exceptions philosophers of science have not shown much explicit interest in the problems of science education' (Ennis 1979, p. 138). Pleasingly, in recent decades, there has been a degree of rapprochement between these fields. Both the theory of science education and, importantly, science curricula and classroom pedagogy have become more informed by HPS. (These themes will collectively be referred to as history, philosophy and science teaching (HPS&ST).) This book contributes to HPS&ST by:

- outlining the arguments for the role of HPS in science education;
- reviewing the history of school science curricula in order to situate the claims of HPS-informed teaching against other approaches to science pedagogy;
- examining the successes and failures of previous efforts to bring HPS into closer connection with the science programme;
- elaborating some case studies where the contrast between HPS and 'professional' or 'technical' approaches to science teaching and curricula development can be evaluated;
- examining some instances of prominent educational debates in science education – constructivism, feminism, multiculturalism, worldviews and nature of science – that can be clarified and informed by HPS;
- outlining the contribution that HPS can make to science-teacher education.

It is hoped that the book will stimulate interest in educational matters among historians and philosophers of science, and encourage interest in historical and philosophical matters among science teachers and, particularly, the educators of science teachers.

When Ennis wrote, in the late 1970s, the exceptions among post-war historians and philosophers who had written on science education included Michael Martin, who published a series of articles (1971, 1974, 1986/1991) and wrote a popular book, *Concepts of Science Education* (1972), on philosophy and science education. Other philosophers and historians of science, who 40 years ago, had written on the subject include Stephen Brush

(1969), Robert Cohen (1964), Yehuda Elkana (1970), Herbert Feigl (1955), Philipp Frank (1947/1949), Gerald Holton (1975, 1978), Noretta Koertge (1969), Ernst Nagel (1969, 1975) and Israel Scheffler (1973). Happily, this situation of relative philosophical and historical neglect has changed, and, in the past few decades, many philosophers of science[1] and historians of science[2] have addressed different of the myriad theoretical, curricular and pedagogical problems of science teaching.

The engagement of philosophers and historians with science education can be seen in contributions to thematic issues of the journal *Science & Education*[3] and in contributions to anthologies such as *History, Philosophy and Science Teaching* (Matthews 1991), *Science, Worldviews and Education* (Matthews 2009), *Epistemology and Science Education* (Taylor & Ferrari 2011) and *Philosophy of Biology: A Companion for Educators* (Kampourakis 2013) and to the three-volume, 76-chapter *International Handbook of Research in History, Philosophy and Science Teaching* (Matthews 2014).

Ennis's six questions are perennial, but they do not exhaust the field of HPS&ST concerns, as can be quickly seen by looking at the titles of the above-cited articles. Philosophers have usefully contributed to pedagogical problems, to curricular discussions and to debate about the following theoretical issues: feminist critiques of science, multiculturalism and science, evaluation of constructivist theory, environmental ethics, the nature of science, science and religion, and so on. One of the theses of this book is that these are not extracurricular or add-on questions for science teachers: philosophy of science is part of the fabric of science teaching, and students acquire or 'pick up' a philosophy of science from their teachers. The issue is just how clearly this is recognised, and how explicitly the philosophical questions are dealt with. It is clear that all of these discussions are improved by philosophical and historical input; indeed, it is impossible to have informed and intelligent discussion of any of the listed theoretical issues without HPS.

History and Philosophy of Science: A Partnership

The conviction of this book is that the philosophy of science needs to be cognisant of the history of science, and the reverse: 'Philosophy of science without history of science is empty; history of science without philosophy of science is blind', as Imre Lakatos memorably expressed the matter (Lakatos 1978, p. 102.) This view was urged against those who saw philosophy occupying an autonomous position, such as Hans Reichenbach, who expressed this latter view in his classic distinction between the contexts of discovery and the contexts of justification in science. For Reichenbach, philosophy was concerned only with the context of justification, whereas history, sociology and psychology are concerned with the context of discovery (Reichenbach 1938).

The proper relation between the history and philosophy of science is much debated, with experts disagreeing on just how necessary the former is for the latter. Hilary Putnam at one point exclaimed that the history of science is 'irrelevant' to the philosophy of science (Suppe 1977, p. 437). The very influential positivist philosopher of science Rudolf Carnap has said of himself that he 'was as unhistorically minded a person as one could imagine' (Suppe 1977, p. 310). Carnap's student, Willard van Orman Quine, has said the same thing; his influential epistemological corpus is devoid of any historical reference (Quine 1960).

On the other side, for those wishing to keep history of science separate from philosophy, questions arise such as: How do we identify the history of science, without some philosophical presuppositions? How do we separate useful history of science from useless history of science, without some prior conception of proper method? It seems that we need to know in advance of writing a history of science what will count as science; if we do not have such a view, then we could presumably set off researching astrology, numerology and stamp collecting, rather than chemistry or geology.

As with many either/or questions, the answer lies somewhere between. The relationship between history of science and philosophy of science has to be interactive. There is ample evidence of history of science being written in the service of philosophical, political and religious commitments. It is notorious that Galileo has become a 'Man for all philosophical seasons' (Crombie 1981), with every methodologist seeing their own favoured methodology being followed by Galileo. Here, history is at best cherry-picked, and the opportunity for history of science to refine or change philosophical commitments is lost. Thomas Kuhn's story of his philosophical transformation, occasioned by having to teach a Harvard general education course on the history of science, is a well-known recent example where history transformed philosophy. Philosophy is required to begin writing history, but it should be capable of being transformed by historical study.[4]

This debate about the place of history is characteristic of many issues in philosophy of science – it would be a rash person who said that the contentious matters of realism, empiricism, causation, explanation, idealisation, truth, falsification and rationality have been settled. But some things regarding the interplay of philosophy and history are agreed upon. Clearly, the history of science should be used to illustrate positions arrived at in philosophy of science. An exposition of the nature of science, of theory evaluation or the ontological commitments of science that did not make mention of Galileo, Newton, Kepler, Lavoisier, Darwin, Mendel, Mach or Einstein, and the scientific controversies they engendered, would be very odd. Unfortunately, philosophy of science courses too often neglect the history of science. Commonly, students read of the debates over scientific methodology engaged in by Carnap, Nagel, Popper, Kuhn, Lakatos, Feyerabend, Laudan, van Fraassen and others, but have to take the contenders' historical interpretations of Aristotle, Galileo, Huygens and Newton on faith; students become spectators to an academic game. What should be a course that enhances appreciation of the scientific tradition and deeper thinking about it can, in the absence of history, become more like a catechism class. This is particularly odd in educational settings where science teachers and science students have heard of the famous names and might expect to see their work figure in any discussion of the nature of science or other philosophical issues occasioned by science.[5] This is *Bildung* in the European tradition.

Science and Liberal Education

The present rapprochement between HPS and science education represents, in part, a renaissance of the long-marginalised liberal, or contextual, tradition of science education, a tradition contributed to in the last 100 years by scientists and educators such as Ernst Mach, Pierre Duhem, Alfred North Whitehead, Frederick W. Westaway, E.J. Holmyard, Percy Nunn, James Conant, Joseph Schwab, Martin Wagenschein, Walter Jung and Gerald Holton. At its most general level, the liberal tradition in education embraces Aristotle's delineation of truth, goodness and beauty as the ideals that people ought to cultivate in their appropriate spheres of endeavour. That is, in intellectual matters, truth should be sought, in moral matters goodness, and in artistic and creative matters beauty. Education is to contribute to these ends: it is to assist the development of a person's knowledge, moral outlook and behaviour, and aesthetic sensibilities and capacities. For liberal educationalists, education is more than the preparation for work; education is valued because it contributes to the cognitive and moral development of both the individual and their culture.

The liberal tradition has a number of educational commitments.[6] One is that education entails the introduction of children to the best traditions of their culture, including the academic disciplines, in such a way that they understand the claims and theories of a specific discipline and know something about the discipline itself – its methodology, assumptions, limitations, history and so forth. A second commitment is that, as far as is possible and grade-level appropriate, the relations of particular subjects to each other, and their relation to the broader canvas of ethics, religion, culture, economics and politics, should be acknowledged and investigated. The liberal tradition seeks to overcome intellectual fragmentation. A third commitment is that education needs to be conducted in an ethical manner, and this is applicable to both classrooms and the wider institutional conduct of schooling. Ethics has both proximal and distal reach.

The liberal tradition maintains that science education should not just be an education or training in science, although of course it must be this, but also an education about science. Students educated in science should have an appreciation of scientific methods, their diversity and their limitations. They should have a feeling for methodological issues, such as how scientific theories are evaluated, how competing theories are appraised, how common controversy is in science, and how scientific argument and debate are engaged in the resolution of these controversies; they should also have an appreciation of the interrelated role of experiment, mathematics, and religious, philosophical and ideological commitment in the development of science. All students, whether science majors or others, should have some knowledge of the great episodes in the development of science and, consequently, of culture: the ancient demythologising of the world picture; the Copernican relocation of the earth from the centre of the solar system; the development of experimental and mathematical science associated with Galileo and Newton; Newton's demonstration that the terrestrial laws of attraction operated in the celestial realms; Darwin's epochal theory of evolution and his claims for a naturalistic understanding of life; Pasteur's discovery of the microbial basis of infection; Einstein's theories of gravitation and relativity; and the discovery of the DNA code and research on the genetic basis of life.[7] They should, depending upon their age, have an appreciation of the intellectual, technical, social and personal factors that contributed to these monumental achievements.

Clearly, all of these goals for general education, and for science education, require the integration of history and philosophy into the science curriculum of schools and teacher education programmes. As will be elaborated in Chapter 12, good teachers of science, and indeed of all subjects, need to know something of the history and philosophy of the discipline they are teaching and be able to enthuse students with these dimensions of science.

History, Philosophy and Technical Education

The rapprochement between HPS and science education is not only dependent on having a liberal view of science education: a good technical science education also requires some integration of history and philosophy into the programme. Knowledge of science entails knowledge of scientific facts, laws, theories – the products of science; it also entails knowledge of the processes of science – the social, technical and intellectual ways in which science develops and tests its knowledge claims. HPS is important for the understanding of these process skills. Technical – or 'professional' or 'disciplinary', as it is sometimes called – science education is enhanced if students know the meaning of terms that they are using; if they can think critically about texts, reports and their own scientific activity; if they know how certain evidence relates or does not relate to hypotheses being tested; if they can intelligently and carefully represent data and argue from data to phenomena; and if they can discuss, argue and advance thinking among their colleagues. These scientific abilities are enhanced if students have read examples of sustained enquiry, clever experimentation, insightful hypotheses and exemplary debates about hypothesis evaluation and testing. Alfred North Whitehead expressed this view of good technical education when, just after World War Two, he said:

> The antithesis between a technical and a liberal education is fallacious. There can be no adequate technical education which is not liberal, and no liberal education which is not technical: that is, no education which does not impart both technique and intellectual vision.
>
> (Whitehead 1947, p. 73)

To teach Boyle's Law without reflection on what 'law' means in science, without considering what constitutes evidence for a law in science, and without attention to who Boyle was, when he lived and what he did, is to teach in a disappointingly truncated way. More can be made of the educational moment than merely teaching, or assisting students to discover, that, for a given gas at a constant temperature, pressure multiplied by volume is a constant. This is something, but it is minimal. Similarly, to teach Darwinian evolutionary theory without considerations concerning theory and evidence, the roles of inductive, deductive and abductive reasoning, Darwin's life and times and the religious, literary and philosophical controversies his theory occasioned is also limited. Students doing and interpreting experiments need to know something of how description of data relies upon theory, how evidence relates to the inductive support or deductive falsification of hypotheses, how real cases relate to ideal cases in science, how messy 'lived experience' connects with abstracted and idealised scientific theories, and a host of other matters that all involve philosophical or methodological concerns. Science has a rich and influential history and it is replete with philosophical and cultural ramifications. An education in science should present students with something of this richness and engage them in some of the big questions that have consumed scientists. Whether these questions are regarded as extra-scientific or intra-scientific is, pedagogically, not very important.

Problems with Science Education

It is internationally recognised that there are problems with science education. Orthodox, technical, non-contextual teaching is largely failing to engage students or to promote knowledge and appreciation of science in the population. There is a well-documented crisis in contemporary science education, evidenced in the flight from the science classroom of both teachers and students, and in the appallingly high figures for science illiteracy in the Western world. This has prompted massive rethinking and reforms in national curricula and science-education policy across the world.

The Flight from Science

In the US, these reform efforts have been rolling on for the past 30 years.[8] Two decades ago, in the US, 70 per cent of all school students dropped science from their programme at the first available opportunity. The American National Science Foundation (NSF) charged that, 'the nation's undergraduate programmes in science, mathematics and technology have declined in quality and scope to such an extent that they are no longer meeting national needs. A unique American resource has been eroded' (Heilbron 1987, p. 556) Recent US reports on college science enrolments are similarly bleak (Ashby 2006). The National Research Council (NRC) says, in its *Next Generation Science Standards*, that:

> The U.S. has a leaky K–12 science, technology, engineering and mathematics (STEM) talent pipeline, with too few students entering STEM majors and careers

> at every level. . . . We need new science standards that stimulate and build interest in STEM.
>
> (NRC 2013)

In Europe, political and educational effort has gone into similar wide-ranging reform initiatives. A 1995 European Commission report said that:

> Traditional science teaching, aiming at the mastery of a strictly logic order, of the deductive system, of abstract notions among which mathematics dominate, seems to paralyse and to make a passive subject of the learner, suffocating his imagination.
>
> (EC 1995, in Dibattista & Morgese 2014)

Acknowledging the failure of science teaching and the flight from science, a 2004 European Commission report was bluntly titled 'Europe needs more scientists' (EC 2004)! The following year, the Commission commissioned a Europe-wide survey that revealed that 50 per cent of adults saw their school science courses as 'not sufficiently appealing', and curriculum and pedagogical changes were called for to redress the science literacy and engagement problems.[9]

Science Literacy

Given the amount of state and private money and resources provided for science education, the levels of adult scientific illiteracy are depressing (Roberts 2007, Shamos 1995). For over four decades, Jon D. Miller and colleagues have conducted a series of NSF-sponsored, large-scale studies on scientific literacy in the US (Miller 1983, 1987, 1992, 2007). For Miller, literacy is measured on two dimensions: knowledge of scientific content and knowledge of scientific processes. The former includes basic knowledge of the meaning of concepts such as 'atom', 'gravity', 'gene' and so forth, and basic factual knowledge. For the latter, literacy requires some knowledge of how science works, what it is to study something scientifically and some basics about experiment and hypothesis testing. In 1985, he judged only 3 per cent of high-school graduates, 12 per cent of college graduates and 18 per cent of college doctoral graduates to be scientifically literate. Among statements to which he asked a representative sample of 2,000 adults to answer true or false were, 'The earliest human beings lived at the same time as the dinosaurs' and 'Antibiotics kill viruses as well as bacteria'. Only 37 per cent of the sample answered the first question correctly, and 26 per cent the second. He concluded that 5–9 per cent of US citizens were scientifically literate (Miller 1992, p. 14). In 2005, his testing was extended to thirty-four nations; pleasingly, the US science literacy rate rose to 28 per cent, but only one country, Sweden, registered an adult science literacy rate above 30 per cent (Miller 2007).[10]

There are, of course, separate arguments about what constitutes scientific literacy[11] and why citizens and educational administrators should be concerned about low and falling levels of scientific literacy. The standard reasons for concern have been:

- *cultural* – science, like music, religion and art, is an important part of our cultural heritage and so needs to be known;
- *vocational* – science, like mathematics and computer competence, is indispensable for a wide range of contemporary occupations and so needs to be mastered;
- *disciplinary* – without a spread of basic scientific knowledge, there will not be a big enough pool of school students who might decide to pursue higher studies and careers in science, or a public supportive of their taxes funding research in scientific disciplines;
- *environmental* – people ought know something about the inhabitants, constitution and processes of natural physical, plant and animal worlds in which they live, and that need to be sustained;
- *utilitarian* – scientific knowledge is useful for myriad everyday life and decision-making.

The final reason reverts back to the 'science of everyday things' that once dominated curricular decision-making, is now making a comeback and is perhaps the most common justification for promoting science literacy and enforcing compulsory school science. As two sociologists of science ventured, science education is helpful because it helps us, among other things, 'know where in the oven to put a soufflé' (Collins & Pinch 1992, p. 150). Yet research suggests that knowledge of disciplinary science has precious little, if anything, to do with everyday decision-making in kitchens, in supermarkets, on the road, in hospitals or most other places, even when explicitly socio-scientific issues are being resolved.[12]

HPS-informed curricula and classroom teaching are surely not the sole solution to these 'problems' of science education, but assuredly they can make the subject more 'appealing', engaging and better connected with other subjects being learned – mathematics, history, philosophy, religion and so on. That it is not immediately useful in the kitchen is not a great drawback; much 'standard' science is not immediately useful either. Apart from better learning of science, a HPS-informed science curriculum can have significant impacts on people's worldviews and their religious and cultural understandings. These impacts are not useless.

Occult and Pseudoscientific Belief

The figures on scientific illiteracy are doubly depressing, as they not only indicate that large percentages of the population do not know the meaning of basic scientific concepts, and thus have little if any idea of how nature works, but because such illiteracy is linked to widespread antiscientific and illogical thought. Gallup polls consistently show that about one-third of

Americans believe in ghosts, telepathy, demonic possession, psychic powers and a range of such completely discredited and dangerous ideas (Gallup & Newport 1991). Newspaper astrology columns are read by far more people than are science columns; the tabloid press, with their Elvis sightings and Martian visits, adorn checkout counters and are consumed by millions worldwide each day. Countless thousands of Internet sites and telephone yellow-page directories offer services such as: astrological therapy, palm reading, aura readings, past-life interpretations, feng shui alignments, future-life happenings, dealing with aliens, clairvoyance, tarot-card readings and the whole gamut of such misplaced and misdirected engagements.[13]

It is unfortunate that these 'alternative' beliefs are frequently associated with artistic endeavour. Communities with the greatest concentration of artists also have the greatest concentration of 'New Age' practitioners. The only town in the Australian state of New South Wales to reject fluoridation of its water supply was the artistic hub of Byron Bay. In Arizona, the town of Sedona is deservedly famous for its scores of art galleries and hundreds of artists, but the town is also awash with purveyors of every kind of occult and psychic therapy and treatment. Everything is for sale: Chakra healing, crystal healing, spiritual acupuncture, past-life therapy, Tao-card analysis, guru sessions and so on. And there are special cosmic energy lines where, for a fee, people can sit at their precise node or vortex and absorb the energy by osmosis.[14] One of the hundreds of alternative business operations claims to:

> have discovered some of the most potent concentrated energy fields (Vortex Phenomena) in the Sedona area to reconnect you with the energetic nurturance of Mother Earth's NEMFs (natural electro-magnetic fields).

Most of the thousands of people in Sedona who, every year, pay money to charlatans and purveyors of nonsense have studied high-school science. One of the tasks of this book will be to understand how 'orthodox' school science makes possible this level of credulity, and how HPS-informed school science might make folk more informed and sceptical, more resistant to nonsense. There is ample 'mystery', wonderment and metaphysics available within science, if it is properly taught.

When thought becomes so free from rational constraints, then outpourings of racism, prejudice, hysteria and fanaticism of all kinds can be expected. For all its faults, science has been an important factor in combating superstition, prejudice and ignorance. It has provided, albeit falteringly, a counter-influence to the natural inclinations of people to judge circumstances in terms of their own experience and self-interest. When people, en masse, abandon science, or science education abandons them, then the world is at a critical juncture. At such a time, the role of the science teacher is especially vital and in need of all the intellectual and material support possible.

No one thinks that just technical science education can 'roll back' the tide of questionable, if not completely nonsensical, personal and cultural beliefs.

There is much evidence that achievement of even high-level technical competence in science is consistent with deeply held, silly beliefs. For example, Sir Oliver Joseph Lodge (1851–1940) was an eminent British experimental physicist, a contributor to the nascent science of radio transmission and creator of the first spark plug for automobiles; nevertheless, he held spiritualist belief about life continuing after death and in the ability of mediums to connect with the deceased in séances.[15] The First Spiritual Temple website says of Lodge that:

> Sir Oliver sought to bring together the transcendental world with the physical universe. He affirmed, with great conviction, that life is the supreme, enduring essence in the universe; that it fills the vast interstellar spaces; and the matter of which the physical world is composed is a particular condensation of ether for the purpose of manifesting life into a conscious, individual form.
>
> (www.fst.org/lodge.htm)

A hundred years after Lodge's less than illuminating musings, Edgar Dean Mitchell, the NASA astronaut who was the sixth person to walk on the Moon after piloting the Apollo 14 craft and who has science and engineering doctorate degrees from MIT, had a similar constellation of 'extra scientific' beliefs. Mitchell has claimed that, on his way back from the Moon, he had a Savikalpa Samadhi experience, during which his soul absorbed the fire of Spirit–Wisdom that 'roasts' or destroys the seeds of body-bound inclinations. After this experience, he conducted in-flight ESP experiments with his friends back home. These experiments were published in the *Journal of Parapsychology*. Mitchell believes a remote healer, Adam Dreamhealer, cured his kidney cancer over the telephone. He also believes in UFOs and interplanetary visitations and believes he has had personal encounters with these extraterrestrials.

There are hundreds of thousands, if not millions, of Lodges and Mitchells for whom first-rate science education seems to have little if any flow-over effect on the rest of their beliefs. This is a particular problem for those believing that science education should have beneficial impacts on students' personal life and for the advancement of culture more generally. This was the expectation of the Enlightenment philosophers and educators, it was John Dewey's hope, and it is the expectation of the American Association for the Advancement of Science (AAAS), which maintained that:

> The scientifically literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognises both its diversity and unity; *and uses scientific knowledge and scientific ways of thinking for individual and social purposes.*
>
> (AAAS 1989, p. 4; italics added)

In its *Benchmarks for Science Literacy*, the AAAS says that education has to: 'prepare students to make their way in the real world, a world in which problems abound – in the home, in the workplace, in the community, on the planet' (AAAS 1993, p. 282).

The unique contribution of the science programme to this more general, problem-solving and society-improving educational goal is the cultivation and refinement of scientific habits of mind. These are meant to 'flow on' from the laboratory bench to the home, workplace, community and planet. For the AAAS, the wider 'planetary' problems are not just material – they are social, cultural and ideological – but application of a 'scientific habit of mind' is necessary for solving these wider problems. They are not solved by listening to gurus, holding Ouija boards or consulting astrologers. A major problem is that scientific habits of mind are poorly cultivated in school science programmes.

The same hopes for flow-on effects energised Nehru's inclusion of the state's duty to promote 'scientific temper' in the first constitution of the independent India. However, 60 years later, despite enormous investment in, and spread of, science education, these expectations have not materialised. As two Indian scholars maintain:

> If one were to pick out three or four most important reasons for the country's backwardness or failure in many areas, the lack of scientific temper would be one of them.
>
> (Bhargava & Chakrabarti 2010, p. 277)

As will be shown in Chapter 2, such Enlightenment hopes depend upon science education embracing the history and philosophy of its subject; without such embrace, there is little chance that learning science will have positive personal, social and cultural effects beyond the classroom; indeed, the contrary. This recognition is one of the elements in the current rapprochement between science education and HPS. This is not to say that HPS-informed education is sufficient for the purpose, but, as Spinoza so wisely said, 'the best should not get in the way of the better'.

Critics of Science

Science has not been without its critics. In the seventeenth century, Giambattista Vico (1668–1744) turned his back on the new science of Galileo and the new mathematics of Descartes in favour of a return to 'ancient wisdom'. Subsequently, many other critics, including the literary Romantics, some religious traditions and various counter-cultural movements, have repeated Vico's stand.[16] Phenomenological philosophers such as Edmund Husserl (1859–1938) criticised the mathematisation of science inaugurated by Galileo because of its failure to grasp the experiential realities of the life world (Husserl 1954/1970). Postmodernist philosophers have attacked the universalist and realist assumptions of science. Prince Charles, the future King of England, has fulminated against Galileo and the modern science tradition he launched, saying that it is materialist, that it objectifies the world and that it is 'an affront to the world's sacred traditions'.[17] After criticising the two-century-old marriage of science and commerce, he opined:

> This imbalance, where mechanistic thinking is so predominant, goes back at least to Galileo's assertion that there is nothing in Nature but quantity and motion. This is the view that continues to frame the general perception of the way the world works and how we fit within the scheme of things. As a result, Nature has been completely objectified – 'She' has become an 'it' – and we are persuaded to concentrate on the material aspect of reality that fits within Galileo's scheme.

It is not just outsiders who criticise science. Glen Aikenhead, a senior Canadian educator and leading figure in international science-education research, has stated that, 'the social studies of science' reveal science as: 'mechanistic, materialist, reductionist, empirical, rational, decontextualised, mathematically idealised, communal, ideological, masculine, elitist, competitive, exploitive, impersonal, and violent' (Aikenhead 1997, p. 220).

It is imperative for science teachers to identify what is correct in these critiques, but also what is incorrect. If the claims of phenomenologists, postmodernists, Prince Charles and supposedly the social studies of science are accepted *in toto*, then the standard purposes and justifications of science teaching have to be abandoned, along with at least the compulsory teaching of science. Does anyone want children learning something that is exploitive, competitive, violent and destructive of comfortable worldviews? Clearly, the appraisal of these claims requires some knowledge of HPS, as this is precisely what the critics appeal to. The arguments of this book are that HPS can defend the core principles and practice of science, but also can contribute to the much-needed improvement and reform of science curricula and teaching.

Curriculum Developments

The HPS&ST programme is energised because of curriculum developments that, in the past few decades, have been instigated by numerous government and educational bodies. These will be documented in some detail in Chapter 3. Among these have been the AAAS in two of its very influential reports, *Project 2061* (AAAS 1989) and *The Liberal Art of Science* (AAAS 1990); the US NRC, with its *Next Generation Science Standards* (NRC 2013); the British National Curriculum Council (NCC 1988); the Science Council of Canada (SCC 1984); the Danish Science and Technology curriculum; and The Netherlands' PLON programme. In all of these cases, HPS is not simply another item of subject matter added to the science syllabus; what is proposed is the thesis of this book, namely more general incorporation of HPS themes into the content of curricula.

The AAAS provides a nice summation of the foregoing curricular initiatives when it says:

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

It should be obvious that, for the realisation of the aims of all of these curricula, there needs to be HPS input into documents, teaching materials, assessment schemes, textbooks and teacher education.

Conclusion

Science and its associated technology are the defining features of the modern world; that they should be better understood is an educational truism. The inclusion of HPS in curricula, teacher education and classroom lessons does not, of course, provide all the answers to the problems of modern education – ultimately, these answers lie in the heart of culture, politics and the economic organisation of societies. However, HPS has a significant contribution to make to improving science teaching and learning and, consequently, personal and social flourishing. This contribution can be itemised as follows:

- HPS can humanise the sciences and connect them to personal, ethical, cultural and political concerns. There is evidence that this makes science and engineering programmes more attractive to the many students, and particularly girls, who currently reject them.
- HPS, particularly basic logical and analytic exercises – Does this conclusion follow from the premises? What do you mean by such and such? – can make classrooms more challenging, and enhance reasoning and critical thinking skills.
- HPS can contribute to the fuller understanding of scientific subject matter – it can help to overcome the 'sea of meaninglessness', as Joseph Novak once said, where formulae and equations are recited without knowledge of what they mean or to what they refer.
- HPS can improve teacher education by assisting teachers to develop a richer and more authentic understanding of science and its place in the intellectual and social scheme of things. This has a flow-on effect, as there is much evidence that teachers' epistemology, or views about the nature of science, affect how they teach, the message they convey to students and, ultimately, the epistemology of students.
- HPS can assist teachers in appreciating the learning difficulties of students, because it alerts them to the historic difficulties of scientific development and conceptual change. Galileo was 40 years of age before he formulated

the modern conception of acceleration; despite prolonged thought, he never worked out a correct theory for the tides. By historical studies, teachers can see what some of the intellectual and conceptual difficulties were in the early periods of scientific disciplines. This knowledge can assist with the organisation of the curriculum and the teaching of lessons.

- HPS can contribute to the clearer appraisal of many contemporary educational debates that engage science teachers and curriculum planners. Many of these debates – about constructivist teaching methods, multicultural science education, feminist critiques of science, issues about the relation between science and religion, environmental science, enquiry learning, science–technology–society curricula, teaching controversial issues such as evolution, and so forth – make claims and assumptions about the history and epistemology of science, or the nature of human knowledge and its production and validation. Without some grounding in HPS, teachers can be too easily carried along by fashionable ideas that, later, sadly, 'seemed good at the time', but that wreck educational and cultural havoc.

Notes

1 See at least: Mario Bunge (2000, 2003, 2011), Martin Carrier (2013), Hasok Chang (2011), Alberto Cordero (1992, 2009), Richard Grandy (1997), Rom Harré (1983), Gürol Irzik (2013, 2011 with Robert Nola, 2014 with Robert Nola), Peter Kosso (2009), Hugh Lacey (2009), Peter Machamer (1992), Martin Mahner (2012, 2014, 1996 with M. Bunge), Robert Nola (1997, 2003, 2005 with Gürol Irzik), Robert Pennock (2002), Cassandra Pinnick (2005, 2008), Demetris Portides (2007), Jürgen Renn (2013), Michael Ruse (1990), Harvey Siegel (1979, 1989, 1993, 1997, 2004), Peter Slezak (2000, 2014), Wallis Suchting (1992, 1995), Paul Thagard (2010 with S. Finlay, 2011) and Emma Tobin (2013).

2 See at least: Fabio Bevilacqua (1996 with E. Giannetto), William Brock (1989, 2014 with Edgar Jenkins), John Hedley Brooke (2010), Ricardo Lopes Coelho (2007, 2009), David Depew (2010), John Heilbron (1983), Mercé Izquierdo-Aymerich (2013), Helge Kragh (1992, 1998, 2014) and Cibelle Celestino Silva (2007).

3 See at least: *Hermeneutics and Science Education*, 1995, 4(2); *Religion and Science Education*, 1996, 5(2); *Philosophy and Constructivism in Science Education*, 1997, 6(1–2); *Galileo and Science Education*, 1999, 8(2); *Thomas Kuhn and Science Education*, 9(1–2); *Constructivism and Science Education*, 2000, 9(6); *Science Education and Positivism: A Re-evaluation*, 2004, 13(1–2); *Models in Science and in Science Education*, 2007, 16(7–8); *Feminism and Science Education*, 2008, 17(10); *Science, Worldviews and Education*, 2009, 18(6–7); *Darwinism and Education*, 2010, 19(4–5, 6–8); *Philosophical Considerations in the Teaching of Biology*, 2013, 22 (1–3); *Philosophical Considerations in the Teaching of Chemistry*, 2013, 22(7); *Mendel, Mendelism and Education*, 2015, 24; *Conceptual Change in Science and in Science Education*, 2014, 23.

4 Some useful discussions of the connection between history of science and philosophy of science can be found in Hacking (1992), Lakatos (1971), McMullin (1970, 1975), Shapere (1977) and Wartofsky (1976).

5 Some of the historical texts with introductions can be read in Matthews (1989).

6 There is a large literature on the theory and practice of liberal education. Sometimes, it is given the name 'general' or 'humanistic' education. Peters (1966, Chapters 1, 2) and Bantock (1981, Chapter 4) are useful introductions to these traditions.

7 The AAAS in its *Science for All Americans* lists ten episodes in history that have had major social and cultural impact in the West and beyond, and that should be appreciated by all citizens (Rutherford & Ahlgren 1990, Chapter 10).

8 The most visible and influential have been the NRC's *National Science Education Standards* (NRC 1996), *Inquiry and the National Science Education Standards* (NRC 2000), *America's Lab Report* (NRC 2006), *Taking Science to School* (NRC 2007), *A Framework for K-12 Science Education* (NRC 2012) and *Next Generation Science Standards* (NRC 2013); the AAAS's *Science for All Americans* (AAAS 1989), *The Liberal Art of Science* (AAAS 1990) and *Benchmarks for Science Literacy* (AAAS 1993).

9 The research literature on European science education reform, and especially the place of HPS in those reforms, is reviewed in Dibattista and Morgese (2014).

10 Miller's research is reviewed in Anelli (2011), Hobson (2008) and Trefil (2008, Chapter 6).

11 See, among others: DeBoer (2000), Laugksch (2000), Roberts (2007) and Shamos (1995).

12 On this, see: Chapman (1993), Feinstein (2011) and Wynne (2007).

13 The most sustained recent discussions of paranormal and pseudoscience belief are by Carl Sagan (1997) and Michael Shermer (1997). See also Mario Bunge (2011) and contributions to *Science & Education* 2011, 20(5–6), a thematic issue on Pseudoscience. A classic historical study of the subject was published 100 years ago by W.E.H. Lecky (Lecky 1914).

14 In 2014, folk were charged US$200 per hour to so sit, and it cost much the same for most other astro/psychic/out-of-world services in Sedona.

15 Oliver Lodge was just one of hundreds of prominent 'men of science' who embraced spiritualism and various other psychic movements in the late-nineteenth and early-twentieth centuries. The Society for Psychical Research has 2,710 letters written to Lodge by a credulous public. The former Catholic priest and professor of philosophy Joseph McCabe (1867–1955) wrote a convincing critique of Lodge's spiritualist–theological–philosophical edifice (McCabe 1914). Unfortunately, McCabe's voluminous publications in theology, philosophy, church history and popular science are now largely unknown, but see Cooke (2001).

16 A good account of 'Science and Its Critics' can be found in Passmore (1978), and in contributions to Gross *et al.* (1996) and Koertge (1998).

17 A lecture delivered at the Oxford University Centre for Islamic Studies in June 2010. See: www.princeofwales.gov.uk/media/speeches

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